

University of Alberta

**USING COST ASSESSMENTS OF PLANNING UNCERTAINTIES TO DIRECT
FOREST MANAGEMENT INFORMATION COLLECTION**

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial
fulfillment of the requirements for the degree of **MASTER OF SCIENCE**
in

FOREST ECONOMICS

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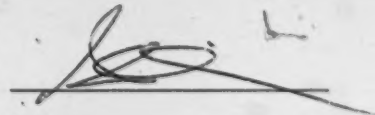
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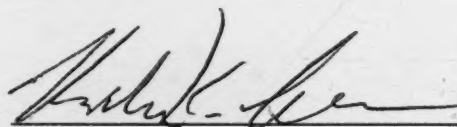
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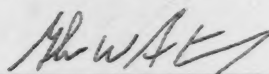
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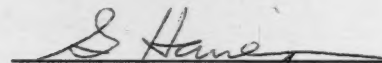
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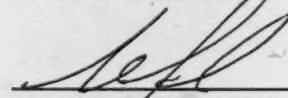
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ABSTRACT

There are two important contributions from this project. The first contribution is a framework to direct information collection according to where reducing uncertainty may have the greatest benefit. The second contribution is an investigation into how stand structures, interest rates and institutional constraints may affect such benefits. The results show that benefits are diminished by a positive interest rate and increase as the sustained yield constraints are relaxed. The key result is that significant benefits from reducing uncertainty exist in all scenarios except mature forests with values discounted by a 6% interest rate. However, the Alberta forest industry operates on mainly mature land bases and faces interest rates of at least 6%. Since, within this framework, industry may not have incentive to invest in uncertainty reduction, there may be an argument to have more government responsibility for research and data collection.

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CHAPTER 1 INTRODUCTION

In the forestry sector, there are numerous sources of uncertainty in planning and decision-making. Knowledge of biological patterns and processes and responses to forest management are limited (Pearse, 1990). Furthermore, "risk of losses from fire and other causes also contribute to the uncertainty in forestry decision-making" (Pearse, 1990). Also, political constraints, policy specifications and future technological innovations can be unclear (Marshall, 1987). These uncertainties and others are all compounded by the long-term planning horizon the forest sector faces.

The mistakes that may ensue can have potentially costly impacts. Therefore, methods have been developed that attempt to incorporate these uncertainties into optimization solutions (for example, Eid, 2000; Ellis *et al.*, 1997; Weintraub and Abramovich, 1995; Thompson and Vertinsky, 1991; and Weetman, 1991). Eid (2000) has proceeded a step further and provided a starting point for "decision oriented inventory planning", whereby "alternatives for inventory design and intensity are based on considerations with respect to inventory costs as well as net present value-losses".

To our knowledge, the study by Eid (2000) is the only literature that attempts to make a link between assessing the potential costs of uncertainty, and influencing the direction of information collection so as to reduce those uncertainties. Such a linkage may be important, as it could also link the needs of industry and society to the research community. Broderick *et al.* (1991) have suggested that professional foresters rarely "have an opportunity to relay their information needs back to the research community". Similarly, Andersson *et al.* (2000) pointed to a need to pursue forest policy and research in a context where the needs of society, the public and the forest owners meet.

Instead of using the potential costs of uncertainty to influence research topic selection, forestry research topics appear to be more commonly chosen according to researcher interest. Funds tend to go to projects where there is recognized expertise or to areas that researchers or research funders think may be important. In addition, media coverage that brings certain aspects of forestry into the public eye can influence where research dollars are spent. Moreover, extrinsic factors such as the four- to five-year political rotation and the development of international agreements, such as the Kyoto Protocol and the Montreal Process, influence the direction of research in forest management. While current research selection methods do provide valuable scientific knowledge, these methods could perhaps be improved with explicit consideration to the benefits of reduced uncertainty.

This research project follows from Eid (2000). The purpose is to develop a framework to provide more explicit information for research topic selection and data collection in forest management. The approach is based upon the idea that one value of information results from reducing costly mistakes.¹ For example, increased forest growth and yield knowledge could reduce mistakes in volume projections. As such, research topic selection and data collection can be driven, in part, by the benefits of reduced uncertainty relative to the costs of the gathering information.

Although the principles presented here apply to any forest resource, they are applied here in the context of timber supply. By simulating differing patterns of available timber supply over time given current and potentially reduced levels of uncertainty, one

¹ There are two principal ways that benefits from forestry research are realized. Firstly, research can give rise to innovation resulting in new products or processes (Hyde, 1989; Globberman *et al.*, 1999). Secondly, research can cultivate existing science by improving current knowledge or reducing uncertainty (Eid, 2000; Wang and Huang, 2000; van Kooten *et al.*, 1992). Of course, innovation and reduced uncertainty are not mutually exclusive benefits.

can ask, how much can information reduce uncertainty thereby reducing mistakes in timber supply projections? Also, what are the benefits of reducing mistakes in timber supply projections within the context of sustained yield policies? This process provides the opportunity to examine how the benefits of reducing uncertainty² are influenced by key factors such as existing age-class structures, interest rates, the stringency of sustained yield constraints, and capital cost implications. Finally, this project will attempt to address the gap in information transfer from foresters to academia through a process that links information on timber supply model parameters to provide guidelines for researchers.

The thesis is organized as follows. Chapter 2 briefly discusses how the project fits within the broader context of the economic value of information. This discussion follows with a review of the status of forestry research in Canada, an examination of forestry research selection methods used both in Canada and the United States, and consideration of the effectiveness of these methods. The influence of media and the role of extrinsic factors on research topic selection is reviewed. The chapter closes with a discussion on uncertainty and the use of expected values in forest planning, and the concept of using the benefits of adaptive management to direct research topic selection. Chapter 3 presents a framework to model the effects of uncertainty and the effects of reducing uncertainty. In Chapter 4, the framework is applied to an empirical case study

² At this point it is appropriate to make a distinction between uncertainty and risk. While both states imply a lack of certainty regarding an outcome, risk assumes that one can assign probabilities associated with different possible outcomes. The distinction is made because in the timber supply runs in Chapters 3 and 4 there is always an underlying probability assessment. So, although the thesis begins by discussing uncertainty assessments as a tool for selecting research topics, and much of the literature review revolves around a discussion of uncertainty, the decision framework actually makes use of risk assessments. However, to maintain continuity, in Chapters 3, 4 and 5 a lack of knowledge is referred to as "uncertainty", even though technically it should probably be called "risk".

that models the effects of increased data collection to reduce uncertainty. Chapter 5 discusses an approach for a more subjective case study that could model the effects of research, as opposed to data collection, to reduce uncertainty. Lastly, conclusions and implications from the study are presented in Chapter 6.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

For the purposes of this literature review, data collection and research are treated somewhat analogously. Indeed, both processes can improve current knowledge and reduce uncertainty. In Chapters 3, 4 and 5, however, a point is made to distinguish between the two processes. Data collection involves sampling and measurement, while research involves hypotheses and experimentation. Because the method of gaining new information differs, the process to model the effects of uncertainty reduction also differs.

2.2 The Value of Information: A Context for this Study

Selecting research topics according to where uncertainty reduction will have the greatest benefit involves estimating the value of increased information. There is a large body of economic literature on the value of information. The expected value of information is defined as "the difference in the expected payoff of decisions using (increased) information and the payoff using the currently available information" (Karnon, 2002). Hammitt and Shlyakhter (1999) provide further explanation:

The expected value of information depends on prior knowledge about the parameter, characteristics of research opportunities that can refine the prior information, the available decision options, and the utility or loss function. Hammit and Cave (1991) identified four heuristic factors that contribute to understanding the EVI: *uncertainty* (about the parameter value), *informativeness* (the extent to which current uncertainty may be reduced), *promise* (the probability that improved information will result in a different decision and the magnitude of the resulting gain), and *relevance* (the extent to which uncertainty about the parameter contributes to uncertainty about which decision option is preferred).

The framework presented here has factors similar to the first two listed by Hammit and Cave; parameter uncertainty is examined, as is the extent to which that uncertainty may be reduced. However, the framework differs somewhat in the third and fourth factors, "promise" and "relevance". This is due to the modeling procedure used here, where timber supply is determined by rule rather than decision. That is, uncertainty in a parameter rules the harvest level as opposed to influencing decisions about the harvest level; this is explained in more detail in Chapter 3.

2.3 Background on Canadian Forestry Research

The Canadian forest industry is continually growing and changing in concert with regional, national and global trends in the demand for forest products and, more recently, the demand for sustainable management of forests. Canada is also a major contributor to an ever-growing body of forestry research. A review of recent Canadian forestry research publications helps quantify this statement and provides some context for this study.

Watts and Kozak (2000) summarized Canada's financial commitment to forestry research. They estimated that between the Federal and Provincial governments, several research institutes (Forest Engineering Research Institute of Canada, Forintek Canada Corp., and Pulp and Paper Research Institute of Canada), and three educational institutes (Wildlife Habitat Canada, National Aboriginal Forestry Association and the Prince Edward Island Wildlife Federation), \$235.2 million were spent on forestry related research in Canada in 1999. The bulk of these funds (65.4%) went towards forestry

research, and from this 19.5% funded pulp and paper research and 13.7% funded the wood products sector.

Brassard and Page (1994) conducted a survey of all Canadian forestry-related publications listed in *Forestry Abstracts* from 1987 to 1992. *Forestry Abstracts*³ is an annual worldwide guide to forestry research publications; it derives abstracts from the Centre for Agriculture and Biosciences International (CAB) ABSTRACTS database. The authors found that over the fifteen-year period Canada's forestry research publications output remained steady at approximately 6% of the world total. Averaged over the fifteen years, 44% of these were federally produced publications, 37% university publications, 13% provincial publications and 6% other. Table 2-1 summarizes the changes in research subject matter over the fifteen-year time period.

Table 2-1 Percentage of Canadian publications in Forestry Abstracts by subject matter categories (Brassard and Page, 1994).

Subject matter category	1978-82	1983-87	1988-92	Total 1978-92
General	10	10	8	9
Silviculture	22	19	23	21
Forest mensuration and management	9	10	7	8
Physical environment	7	10	11	10
Fire	4	3	2	3
Plant biology	7	9	18	12
Genetics and breeding; variation; evolution	3	5	6	5
Mycology and pathology	8	9	8	8
Insects and other invertebrates	21	19	13	17
Range/game and wildlife/fish	6	2	2	3
Protection/conservation	4	3	2	3
Dendrochronology and dendroclimatology	<1	<1	<1	1
Total	100	100	100	100

³ Available at <http://tree.cabweb.org/Journals/forabst.htm>.

According to Table 1, research on silviculture and invertebrates consistently dominated the subject matter from 1978 to 1992. A closer examination into how research topics are chosen and how funding is allocated may provide insight into why some research topics are chosen over others.

2.4 Research Selection Systems

There are many publications documenting forestry research topic selection methods. This section reviews several different Canadian and American proceedings for selecting research topic priorities. The results of these proceedings are presented and discussed.

2.4.1 Forestry Research Advisory Council of Canada

The Forestry Research Advisory Council of Canada (FRACC) has prepared annual overviews of forest research priorities across Canada for the Canadian Council of Forest Ministers (CCFM) since 1989. The CCFM is made up of federal, provincial and territorial forest ministers whose purpose is to:

...provide cooperation in the development of Canadian positions on international forest issues affecting provinces and territories; exchange information and views on international matters relating to Canada's forests; and, consult provinces and territories on international forest matters that touch on their responsibilities for forest management (Canadian Council of Forest Ministers, 2000a).

The overviews that FRACC generates are based on solicited input from provincial and territorial forest research bodies, who are asked, in surveys, to list their top five priorities for forest research. Two of the surveys are looked at here; one was conducted

in 1991 and the other in 1993. In the 1991 survey, advisory groups across the country responded to the Council's following survey questions (Forestry Research Advisory Committee of Canada, 1992; the 1993 survey was similar to this one):

1. Name the five top forest research priorities for work needed to ensure a sustainable flow of all forest benefits.
2. Of the five topics named, identify those that are adequately funded and supported.
3. Identify those that are not adequately funded and supported.
4. If possible, suggest how to fund work that is not adequately funded.
5. Describe emerging issues that are likely to affect future forest research priorities.
6. Comment on the adequacy of forest research in your area.

Table 2-2 lists the priorities that were identified and ranked (1 through 10, highest to lowest) in both the 1991 and 1993 surveys.

Table 2-2 Comparison of identified research priorities (Forestry Research Advisory Committee of Canada, 1994; Forestry Research Advisory Committee of Canada, 1992).

Priority rating	1991	1993
1	Environmental effects of forest management	Integrated forest landscape management systems and decision support
2	Pest and weed management and alternatives to chemicals	Inventory, growth and yield, ecological site classification
3	Decision support for management, silviculture and land use	Ecosystem functioning, soil and biodiversity conservation
4	Ecological knowledge for intensive forest management	Pest and weed management and alternatives to chemicals
5	Integrated resource management systems	Ecological effects of natural and human-caused disturbances
6	Site-productivity classification systems	Lower-cost silviculture and harvesting, natural regeneration
7	Growth and yield data for managed and unmanaged stands	Forest fire management and control
8	Silvicultural and harvesting methods and cost reduction	Socio-economic knowledge and resolution of resource use conflicts
9	Forest fire management and control	Mixedwood management
10	Tree improvement and genetics	Incentives for private investment

The FRACC surveys generate useful overviews of research priorities as they evolve over time, however some concerns come to light. First, the authors compared the 1991 priorities with those of previous years and expressed concern that priorities are changing at rates that research programs cannot adjust to quickly enough (Forestry Research Advisory Committee of Canada, 1992). Indeed, the top priority identified in 1991, Environmental Effects of Forest Management, was not even mentioned as a priority in 1993. However, the authors then stated in the 1993 report that research priorities are "not changing too quickly for research agencies to adapt". This change in

outlook may be due to recent adaptations in research programs, but it may also reveal possible limitations in this process of selecting priorities. Do opinions regarding research priorities really change to such a degree over a two-year period, or is the survey overly sensitive and simply not capturing long-term trends in opinions?

Secondly, in the 1991 survey results, Alberta respondents noted that their "top five priorities are inadequately supported, but that the program is well rounded, with a balance of basic, applied, environmental and forest management research," (Forestry Research Advisory Committee of Canada, 1992). In the 1993 survey, however, Alberta respondents described forestry research as "polarized, not well coordinated with industry, (lacking) long term strategy, short term oriented, (lacking) well defined scientific and operational values, (and lacking) accepted uniform project evaluation," (Forestry Research Advisory Committee of Canada, 1994). This shift in response may be due to inconsistent opinions regarding research or due to inconsistent research programs per se. In either case, it reinforces the need for a more concise method of selecting research priorities.

2.4.2 The Alberta Research Council

The Alberta Research Council (ARC) is a provincial science and research organization that performs applied research and development in the areas of agriculture, energy, environment, forestry, health and manufacturing industries (Greenway, 2000). The ARC hosted a series of Mixedwood Workshops in April 1998 and in January 2000 to identify forestry research priorities. ARC workshop members held brainstorming sessions to identify areas where they felt further mixedwood research was needed and

subsequently ranked each issue in order of importance (Greenway, 2000). Participants in the 2000 workshop identified the following topics as research priorities:

1. Predict natural and treatment successional pathways
2. Modeling mixedwood succession with respect to yield/curves
3. Review of silviculture research
4. Economic analysis of treatment options
5. Site capability of different species on a site
6. Critical intervention points

One disadvantage to using a consultation process such as this one to reach consensus, is that consensus is often achieved at the cost of creating a document with broad and vague guidelines. Guidelines that are too prescriptive, however, can inhibit the generation of good, basic research.⁴ Another possible drawback to the ARC process arises from the fact that the participants worked in groups, which raises the concern that each person's opinion had the potential to be influenced by the group. As a result, the group could have potentially biased the results of the workshop or broadened the scope of the results.

The ARC research priorities appear vague when compared to those identified by the FRACC. What makes the FRACC priorities more definitive? Possibly it is because the FRACC compiled and ranked lists of priorities that were identified individually by

⁴ B. Taylor, Science Advisor, Science Branch, Canadian Forest Service, personal communication, November 28, 2000.

forestry experts; the procedure involved no group decisions and hence there was no need for compromise or consensus.

2.4.3 British Columbia Forest Health Committee

In an attempt to provide more specific research guidelines within the topic of forest health, the British Columbia Forest Health Committee (BCFHC) requested a survey be developed "to elicit forest health research priorities from various forest research agencies and prime users of forest health research results" (Nevill *et al.*, 1995). In response to this request, Nevill *et al.* (1995) developed such a questionnaire and distributed it to forest management agencies, forest industry and other research agencies. Participants were asked to rank what they thought were the 10 most important forest health problems in their region. For each problem, they were also asked to rate the priority and identify the type of research needed. The survey results were evaluated and compiled into lists of research priorities in the areas of forest diseases, forest insects and mammal pests. The authors compared these lists with current research and found that many topics that had been judged as high priority were receiving little or no research attention in BC. Using these lists, they prepared a more broad-based list of the top eight research priorities that they considered would address forest health:

1. Alternative silvicultural systems
2. Standardization/coordination of survey methodology
3. Hazard rating/decision support systems
4. Quantification of pest-caused losses

5. Cost-benefit analysis
6. Ecosystem approach to forest health
7. Cooperation between different research agencies
8. Peer review

This system relies on expert opinion to select research priorities, thus reinforcing the trend seen in previous systems that also rely on subjectivity. While subjective methods do provide valuable input regarding research priorities, these methods could perhaps be improved with explicit consideration to the benefits of reduced uncertainty

2.4.4 Northeast Forest Resources Extension Council

Broderick *et al.* (1991) reviewed a research topic selection survey by the Northeast Forest Resources Extension Council (NEFREC). NEFREC is a council created in 1983 to identify, prioritize and design educational programs to address emerging renewable resource issues of regional importance. In 1986, the NEFREC sent out a survey that petitioned opinions on research priorities from foresters in the northeastern United States. The open-ended questionnaire contained 13 category headings and respondents were asked to list, under the appropriate heading, problems or questions they felt needed to be addressed by research. Those research topics that were listed five or more times by individual respondents were used as a platform from which to create a more specific list of potential research topics categorized under 11 subject headings. In 1989, an additional survey was conducted based on this list, and respondents were asked to rate each topic according to whether it required further research. Respondents in 1989

were asked to also give their opinions on how they would allocate research budgets among the 11 major subject headings. The results of the 1989 survey revealed the following forest research priorities:

1. Forest decline
2. Economics and marketing
3. Regeneration
4. Silviculture
5. Insect and disease problems
6. Harvesting technology

Again, there are concerns with these methods. Namely, the authors noted a tremendous diversity of opinion in the survey. "Every potential research topic on the questionnaire was rated as being an 'extremely high need' by some and 'not needed' by others" (Broderick *et al.*, 1991). In addition, "t-tests revealed no statistically significant difference ($p=0.05$) between any two adjacent topics on the ranked list" (Broderick *et al.*, 1991). This insignificance detracts from the value of having a prioritized list of topics. These results exemplify some of the shortcomings associated with subjective methods to select research priorities.

2.4.5 MAPLE Scoring Model

The MAPLE scoring model was adapted from Australia's Commonwealth Scientific and Industrial Research Organization by Simkus *et al.* (1996) to assist in setting forest research priorities. Given a set of research proposals, the process involves

leading users through a framework of questions to produce a score for each project. The model is based on four criteria; research potential rating, research capacity, potential benefits and the ability to capture these benefits. The research potential and research capacity criteria, on the left side of the diagram (Figure 2-1), refer to the size of the initiative and the usefulness of research results anticipated from the proposed project. The benefits and ability to capture benefits criteria, on the right side of the diagram (Figure 2-1), refer to expected "net economic, environmental, and social advantages which may be realized in Canada as a direct result of the project". A separate worksheet for each of the four criteria provides decision makers with a set of questions that are answered with a scoring system. These ratings are given relative to other projects under consideration, and are converted to a project score (Figure 2-1). Decision makers then use these scores within the MAPLE spreadsheet framework to help create a research portfolio.

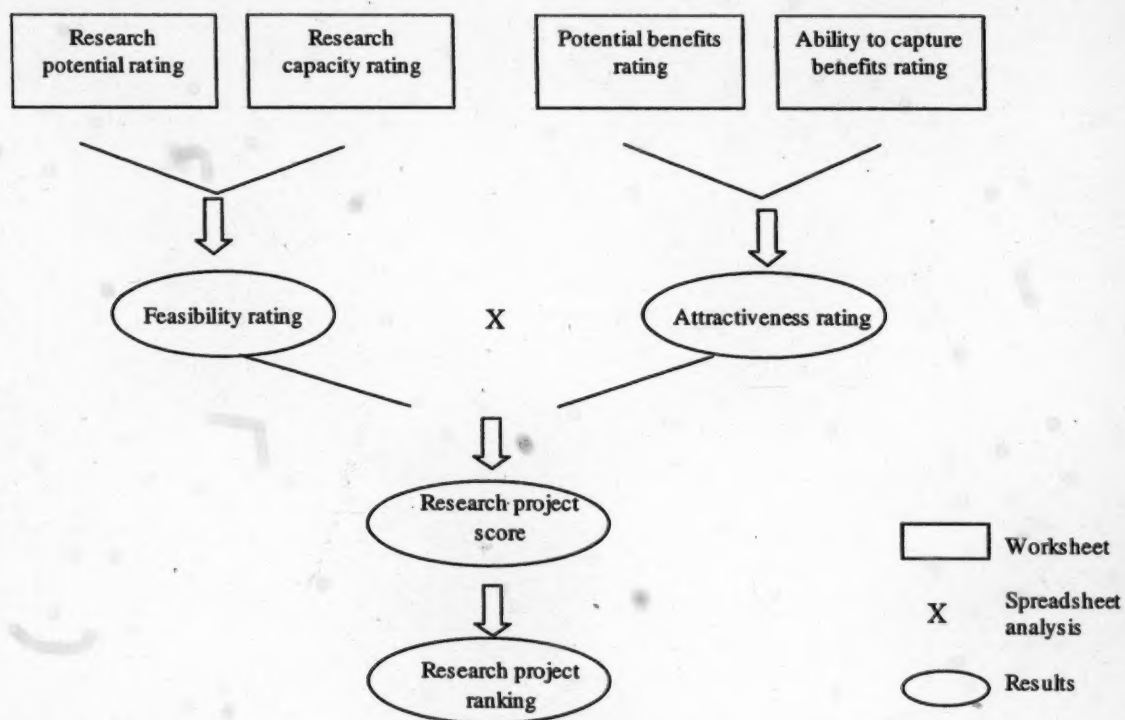


Figure 2-1 Calculating the research project score using MAPLE (Simkus *et al.*, 1996).

Similar to previous methods, the MAPLE Scoring System solicits input from experts to rank research priorities. However, it differs by providing an explicit framework within which the expert opinions can be organized. This framework may mitigate potential problems associated with subjective topic selection. However, since the MAPLE model prioritizes topics from an existing group of research proposals, it provides no means to develop an initial list of priorities from which researchers could select topics.

2.4.6 The Media

The news media can influence the selection of forestry research topics when it brings certain aspects of forest science and environmental issues into the limelight. In turn, members of the public can pressure governments and businesses to invoke change in perceived significant issues. Without belittling the role of public opinion in forest management decisions, it is important to realize the potential for miscommunication between science, the media and the public, and thus the potential for a misinformed public. Powell and Liess examined case studies of communication between the science, the media and the public, in the book, *Mad Cows and Mother's Milk* (1997). They say that although many members of the public look mostly to the media for scientific information, the media often misrepresent, partially or wholly, environmental issues and risks. Marshall (1987) suggested that "frequently the public is not well informed and lacks the necessary training to understand the biological and economic processes of the forest".

There are various suggested reasons for the potential misrepresentation of scientific information in the media. From Lichter *et al.* (2000),

...the difficulty of providing an accurate recounting of reality is exaggerated for science journalism, due to the complexity of the subject matter and the lack of knowledge among the news audience. Yet policy makers and the general population alike rely on accurate reporting of scientific controversy and consensus to help them plan, carry on, and make sense of their daily lives.

Eadie (no date) suggested that communication problems often result when the media translates scientific jargon into laymen's terms, a process that can cloud facts. Eadie further suggested that there is potential for news stories to be influenced by

reporters' opinions, a phenomenon that can lend bias to a story. On a more technical level, the time restrictions reporters can face when producing articles may limit the number of sources a reporter will examine (Eadie, no date).

2.4.7 Extrinsic factors

Extrinsic factors, such as the process of elections and consequent political rotations that occur every three to five years, as well as the impact of national and international agreements, can considerably influence the direction of forestry research. For example, the Kyoto Protocol of 1997 sets targets for the reduction of greenhouse gas emissions. One consequence of these targets is a need for research on "problems associated with the mechanism to transfer land out of agriculture into plantation forest", since the practice of afforestation on marginal agricultural land can increase terrestrial carbon uptake (van Kooten *et al.*, 1999).

Another extrinsic factor that influences forest policy and research is the Montreal Process, which developed a set of criteria and indicators that can be used to measure sustainability of forest management. The first of the six criteria is the Conservation of Biological Diversity (CCFM, 2000b). This criterion alone has influenced the direction of forestry research. For instance, the Canadian Council of Forest Ministers (2000b) suggests:

...with adequate management and research strategies, Canada should be able to maintain its forest biodiversity for future generations. However, more knowledge is required of all three forest biodiversity elements - ecosystems, species and genes.

These extrinsic factors probably have a justifiable influence on forestry research selection because they establish the environment within which forest management

operates. Furthermore, if such factors are incorporated into national policy and international commitments through legislation, the need for compliance warrants the research. However, as the six previous examples of research selection systems show, there is room within this environment for a more explicit approach to selecting topics.

2.4.8 Summary

Every research priority list presented in Section 2.3 includes silviculture as a priority, which may explain why it has dominated Canadian forest research subject matter in the past.⁵ This discussion also reveals several important insights into current research selection systems in forestry, and helps justify the need for a more explicit system.

Consensus building to identify research priorities can result in broad and vague guidelines. Naturally, research priorities developed for a national scale must be fairly broad in order to remain applicable to distinct local regions. However, there may be a need for additional research selection guidelines for local regions that would provide more specific direction. Drawing on the idea of the Maple Scoring System framework, which organizes expert opinions on research priorities, this project will develop a more explicit system to gather information that will aid research topic selection on a smaller scale.

Surveys are often used to solicit opinions from field experts on research priorities; this is a highly subjective method to select research priorities. To the degree that this method will reflect current concerns about forest practices, either from experts, members of the public, or from international agreements, it is a potentially valuable approach.

⁵ Information collected by Brassard and Page (1994) shows that silviculture has dominated forestry research subject matter in the past.

However, there are also inherent weaknesses associated with subjectivity. For instance, Broderick *et al.* (1991) found inconsistencies in survey results. The overwhelming reliance on qualitative input apparent in current research selection systems emphasizes the lack of quantitative analysis that goes into selecting research priorities. This project attempts to reduce subjectivity but by no means eliminates it, since subjectivity is an inevitable element of any human-related activity.⁶ This study takes care to use all subjective inputs in an explicit and carefully framed manner. Furthermore, it incorporates empirical analyses to provide information for research topic selection. In doing so, the current, rather ad hoc, use of subjective input will hopefully be improved.

Inefficiency is apparent when research priorities change too quickly for research agencies to adapt (FRACC, 1992). Paradigms and attitudes are in a constant state of change and will inherently affect year-to-year research priorities. Friedman (2000), of the USDA, believes research inefficiency lies in the fact that there are an "army of proposal writers..., piecemeal attempts to solve problems, scientists addressing problems that do not exist and not addressing ones that do, and managers shooting in the dark while making decisions." Martell (1992) has also addressed such piecemeal approaches, and emphasized a requirement for researchers to directly address practical forestry problems. He added that comprehensive research programs should not only generate new knowledge, but should also help forest managers use new knowledge, otherwise we will continue to "overwhelm forest managers with growing amounts of seemingly

⁶ This proposition was discussed as early as 1844 when Karl Marx wrote that man is a "subjective existence of thought" (Marx, 1844). Matthews (1998) also addressed the use of subjectivity in scientific research. Recognizing that the scientific community tends to regard objectivity as the key that distinguishes "genuine science from pseudo-science", Matthews used arguments and case studies to prove the prevalence and necessity of subjectivity in research. In one such example he asked, "what objective principle underpins the choice of α , the cut-off level for 'significance', or the preference of one frequentist method over another?"

meaningless data that are of little or no practical value." This dilemma could be somewhat minimized with a more focused system, such as the one presented here, to gather information to aid research selection.

Lastly, the media often misrepresent environmental issues, yet still influence the direction of forestry research topics when they act as an information source for members of the public (Eadie, no date; Powell and Liess, 1997). In turn, the public pressure governments and industry to invoke change in perceived significant issues (Lichter *et al.*, 2000). However, the problem of misrepresentation of environmental topics by the media is beyond the scope of this project.

2.5 Uncertainty in Forest Management Planning

This project presents a framework to collect more information for research topic selection that is driven by the benefits of uncertainty reduction relative to the costs of research. The framework is based upon the idea that one of the values of research comes from reducing costly mistakes. This section reviews literature that addresses the effects of parameter uncertainty in forest management planning and the potential benefits of reducing uncertainty.

2.5.1 Effects of Current Uncertainty

2.5.1.1 Sensitivity Analyses

The British Columbia (BC) Forest Service analyzes the effects of variable parameter estimates on timber supply. Timber Supply Area Analysis Reports, which are completed at least once every five years for each timber supply area in BC, each contain

a timber supply analysis and a socio-economic analysis. Their purpose is to examine the short- and long-term effects of current forest management practices on the availability of harvestable timber in supply areas and tree farm licenses throughout BC (British Columbia Forest Service, 1999). The North Coast Timber Supply Area Analysis Report (BC Forest Service, 1999) introduced the issue of forest planning uncertainties by stating that managers cannot be certain that all data accurately reflect the current state of all values in the forest, how the forest will change, or how management activities will affect the forest. The report suggested several ways to deal with this uncertainty. One way is to examine how measured criteria change when inaccurate planning parameters are used; sensitivity analyses that expose the effects of uncertainties on criteria can accomplish this.

One such sensitivity analysis, in the 1999 report, looked at the effects of variation in timber supply volume estimates on annual allowable cut (AAC). Standing timber volume estimates are subject to uncertainty because they are based on extrapolation and on inventory classifications that contain some uncertainty; there is also uncertainty in decay estimates, waste estimates, and breakage during harvest (BC Forest Service, 1999). The report found that a change in current volume estimates by 10% in either direction considerably disrupted harvest levels.

2.5.1.2 Decision Oriented Inventory Planning

Recognizing that little attention is given to uncertainty in forest inventory data or to the effect of that uncertainty on long-term timber production analyses, Eid (2000) presented a way to incorporate uncertainty into Norwegian forest planning. Eid

suggested using "decision oriented inventory planning", whereby the planning process incorporates the uncertainty associated with using erroneous data and expresses the monetary value of inventory information.

Eid considered four inventory parameters: basal area, mean height by basal area, site quality and age. To imitate the random errors of inventories he generated a reference data set (representing the "true forest") comprised of randomly produced variables. He subsequently generated 1500 additional data sets (representing erroneous inventory data) with three levels of random error in the inventory variables; ten percent, fifteen percent and twenty percent. Eid used a timber supply model to conduct projections of timber supply and economic calculations based on the "average tree" of each stand.

In Norwegian forest planning regulations, volume, which is computed with basal area and mean height by basal area, is the only variable with explicit requirements for accuracy. However, Eid found these two parameters did not significantly influence NPV-losses, whilst errors in site quality and age generated large NPV-losses, suggesting a need to change inventory priorities in Norway. Eid also found that a reduction in the simultaneous error level from twenty to fifteen percent would cost less than the gain in NPV, suggesting that investment in more accurate inventory data, especially site quality and age data, would be worthwhile.

2.5.1.3 Subjective Estimates of Uncertainty

van Kooten et al (1992) demonstrated a method to incorporate uncertain growth rates into forest management models in instances where empirical estimates of uncertainty do not exist. Such instances are seen both in managed stands, for which the

effects of management are uncertain, and unmanaged stands, for which age-volume tables, for example, "do not provide information about the variance of stand growth". The authors suggested soliciting expert opinions of parameter uncertainty from tree physiologists and other foresters. This would involve asking qualified experts to describe the most likely, the maximum, and the minimum outcomes of different management regimes on growth rates, utilizing graphical comparisons of various growth functions. These estimates could be used to create triangular probability density distributions around the parameters. The authors touted the usefulness of triangular distributions since, "when there is more than one respondent, fuzzy methods can be used to combine responses. Further, the triangular distribution is easy to understand and construct and can be made asymmetric."

van Kooten et al (1992) proceeded to examine the effects of uncertain growth rates. They found that rotation length decreased as a function of uncertainty in both deterministic and stochastic models, and that flexible harvest policies were preferable in the presence of uncertainty. They suggested that there can be significant savings to society and the private sector when uncertainty is considered in forest planning. Finally, they examined the effects of different discount rates on optimal harvest volumes and found that an increase in discount rate decreased the rotation length.

2.5.2 Reducing Uncertainty

Wang and Huang (2000) found that by increasing stratification they could reduce the uncertainty around timber volume estimates for Alberta's wetland mixedwood (WMX) natural subregion. They developed "...height and site-index models for each (of

Alberta's five) natural subregions... and compared these models to the provincial model developed by Huang (1994)". Only the WMX subregion had height-age curves different from the provincial models. From Wang and Huang (2000),

...large errors in volume estimation occurred when the provincial height and site index model was applied to the WMX natural subregion. At age <50 years, volumes were underestimated by up to 25%. The under-estimation increased with site index. At age >50 years, volumes were under-estimated (by up to 19%) for stands with low site indices, but were over-estimated (by up to 20%) for stands with high site indices. These over- and under-estimates increased with age.

Given that the heights of even-aged stands have been commonly used "as a measure of forest productivity and a 'driving' variable in many growth and yield models", results such as these may generate benefits by measurably reducing uncertainty in timber supply modeling (Wang and Huang, 2000).

In some respects, this is what has happened with site productivity ratings in Alberta.⁷ Under Phase III timber productivity ratings, most areas were grouped into medium productivity classes. With the addition of ecosite based productivity estimates, the distribution has changed with greater representation in good and poor classes. Also, the average value of site index by class has shifted upward.

2.5.3 Benefits from Reducing Uncertainty

2.5.3.1 *Flow of Potential Benefits*

Forest management research to reduce uncertainty can generate benefits to multiple parties, from the landowner (the Crown) and forest companies, to forest product consumers and society. The perspective from which benefits are being measured or

⁷ M. Messmer, Timber Supply Manager, Weyerhaeuser Company Ltd., Edmonton, Alberta, personal communication, 2000.

estimated is important, since these benefits will be distributed differently, to some extent following the distribution of economic rent from forests.

Rent is the return from the timber that is "greater than the amount necessary to keep the resource producing" (Pearse, 1990). The amount and distribution of rent depends on current policies, economic conditions and the political environment. Rent also depends on the starting conditions of a forest; for instance, a juvenile forest and a mature forest are apt to generate very different rent flows. The flow of rent from a forest can be affected by institutional constraints (The Center for International Forestry Research, 1999):

... the royalty, fee or tax or market regime can have a significant effect on how much resource value is generated, and how much of it accrues to an owner. The manager, who may be responsible for any or all of logging, replanting, processing or marketing of the products, will typically enjoy a share of the rent or perhaps a subsidy. Domestic consumers may also share in the rents through consumption subsidies. Rent shares to consumers are typically low, except in instances where entire forest stands have been turned over to communities to manage. Finally, local individuals or communities may be compensated through direct or transfer payments.

2.5.3.2 *Estimating Benefits*

Several methods to measure the benefits of research to reduce uncertainty have been described in literature. McKenney *et al.* (1994) summarized a method adapted from a framework for research priority decision-making by the Australian Center for International Agricultural Research. They modeled potential ex ante benefits of research in a research evaluation database, which "makes use of economic concepts of consumer and producer surplus to estimate the potential welfare effects of research". In a different study McKenney *et al.* (1988) used cost-benefit analyses to estimate the economic

benefits of tree improvement. They took the "difference in total NPV between what plantations would yield if improved planting stock were used as opposed to the use of unimproved stock." They compared this (forest level) value to the costs of research to obtain an estimate of the total net worth of tree improvement from the perspective of industry. Similarly, Eid (2000) compared the NPVs of timber supply projections, based on different error levels in inventory variables, to the associated costs of data collection.

2.5.3.3 *Lag Effect of Research*

Diffusion and the lag effect are additional considerations that can be incorporated into estimates on the benefits of research. Hyde *et al.* (1989) discussed a lag effect whereby research may not realize results until much later. In forestry, this lag may be as long as a timber rotation and can act as a disincentive for forestry research (Hyde *et al.*, 1989). Hoiberg (no date) also pointed out "ex ante research benefits require that sufficient lag-time exists between the initial development of the innovation and its subsequent diffusion".

2.5.4 Summary

The sensitivity analyses by Eid (2000), the BC Forest Service (1999) and van Kooten *et al.* (1992), and the increased stratification by Wang and Huang (2000), embody a fundamental concept of this paper: to analyze the effects of variable parameter estimates. The analyses presented in the following chapters begin with estimates of current and potentially reduced parameter uncertainty via sampling techniques, followed by sensitivity analyses on the effects of current and potentially reduced levels of

uncertainty in the context of timber supply modeling. Examinations into how different institutional constraints may influence the benefits of uncertainty reduction complete the analyses.

These comparisons can be used to establish a link between the sensitivity analyses and research topic selection. This link may be important not only because it will reduce the gap in information transfer from the research community to practicing foresters as discussed by Broderick *et al.* (1991), but also because it will address the presence of uncertainty in forest management planning variables. Furthermore, the link will essentially examine the benefits of adaptive forest management, a paradigm that has recently gained importance in international forest management circles.⁸ The British Columbia Ministry of Forests (2000) defines adaptive management as:

...a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form—"active" adaptive management—employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.

In this project, the benefits of uncertainty reduction are compared in terms of net present values (NPVs)⁹. Since the benefits may, to some extent, follow the flow of economic rent from forests, they are examined from the perspectives of different rent beneficiaries; namely, the private versus public sectors. Also, it is very plausible that benefits may affect rent as it is seen within policy constraints. Therefore, this project examines how benefits may be affected by different institutional constraints, including

⁸ Adaptive management is becoming a widely recognized forest management paradigm. Criteria and Indicators of Sustainable Forest Management (CCFM, 2000a), for example, highlights the need for adaptive management as a component of sustainable forest management.

⁹ McKenney *et al.* (1988) and Eid (2000) conducted similar cost-benefit analyses.

different age-class structures, different interest rates, and varying degrees of sustained yield constraints. Unlike the stand level analyses used by van Kooten et al (1992), the analyses here will be at the forest level, which provides a more appropriate accounting stance for research topic selection. Lastly, the lag effect as discussed by Hyde et al (1989) and Hoiberg (no date) is an important consideration that will be incorporated into the sensitivity analyses.

CHAPTER 3 THEORY AND METHODS

3.1 Introduction

This chapter presents a framework to facilitate decision-making in forest management regarding what, and how much, information to collect. The approach is based upon the idea that one value of information comes from reducing costly mistakes. Such mistakes in forest management planning can be the result of uncertainty in planning parameters. As such, deciding how and where to focus information collection can be driven, in part, by the benefits of reduced uncertainty relative to the costs of collecting information.

Although the principles presented here can be applied to any forest resource, they are applied here in the context of timber supply. Timber supply is relatively straightforward to model, measure and value, it is a relevant commodity to the forest industry, society and the government, and it is easy to visualize. A timber supply model is used to simulate differing patterns of available timber supply over time given current and potentially reduced levels of uncertainty in modeling parameters. Within the context of these sensitivity analyses the following questions are asked: How much can information reduce uncertainty thereby reducing mistakes in timber supply projections? What are the benefits, in terms of net present values (NPVs), of reducing mistakes in timber supply projections within the context of sustained yield policies? This process provides the opportunity to examine how the benefits of reducing uncertainty are influenced by key factors such as existing age-class structures, interest rates, the stringency of sustained yield constraints, and capital cost implications of varying harvest levels. This process will address the gap in information transfer from foresters to

academia by linking information on timber supply model parameters to provide guidelines for researchers. As such, the entire framework will compare the benefits of information collection in forest management and describe conditions that are key in influencing these benefits.

This chapter begins by describing how to select a timber supply parameter to evaluate for potential uncertainty reduction, and how to select an appropriate criterion to gauge the effects of that reduction. Then, five hypothetical timber supply scenarios, in which the effects of uncertainty reduction are modeled, are presented to establish the basic modeling process and expose some underlying principles. Chapter 4 follows with the methods and results of a case study where the modeling process is applied to a more real-world situation. It includes an explanation of how to use existing data to estimate current uncertainty for a parameter, and how to estimate the potential for reducing that uncertainty. Finally, Chapter 5 follows with a discussion on how current and reduced uncertainty can be estimated using professional judgment, instead of existing data.

3.2 Parameter Selection

There are numerous sources of uncertainty in timber supply projections. Uncertainty regarding natural disturbances, biological processes, and economic factors are a few examples. As such, there are numerous parameters in timber supply models that can be examined for potential uncertainty reduction. To help select a parameter, one could survey timber supply modelers from Alberta forest companies and the Alberta government to gather opinions on the most consequential or most problematic parameters in forest planning. In effect, the lists of priorities from the workshops reviewed in

Chapter 2 already provide such information, and using parameters previously identified as research priorities would inherently test the urgency of those 'priorities'.

In the process of selecting parameters, two different types of parameters may be encountered; sampling parameters, for which data is available to calculate current uncertainty, and non-sampling parameters, for which there is no data available to calculate current uncertainty and it may instead be estimated using professional judgment. As an example of both types of parameters, the parameter examined in this paper is projected volume, which is based on growth and yield estimates. There are numerous sources of uncertainty in growth and yield estimates. For instance, growth rates are often inferred from temporary sample plot (TSP) information, there are measurement biases in collecting this information, and many strata are poorly represented in the TSPs. In Chapter 4, projected volume is regarded as a sampling parameter and available temporary sample plot data is used to calculate estimates of uncertainty. In Chapter 5, projected volume is briefly discussed in the guise of a non-sampling parameter.

3.3 Criteria Selection

A criterion is required to gauge the effects of uncertainty reduction. One should select a criterion that is sensitive to the parameter being evaluated and to potential exogenous influences on that parameter. Possible criteria that could be used singly or in combination include operational measures such as annual allowable cut (AAC), stems per hectare or species composition, or other measures such as biodiversity, water quality, wildlife habitat, recreation opportunities, or aesthetics.

The criterion used for the simulations in this chapter and the case study in Chapter 4 are NPVs of AACs. AAC reflects changes in a broad array of planning parameters and is sensitive to a range of variable parameter estimates. This is because harvest levels are calculated based on the extent of the forest land base, growth rates, accessibility, economic conditions, environmental considerations, silviculture investments and management objectives (CCFM, 2000a). Furthermore, AAC is a relevant criterion for forest companies in Alberta since it is a means for regulating the amount of timber permitted to be cut during a given time period from a specified area (CCFM, 2000a).

3.4 Estimating Current and Potentially Reduced Parameter Uncertainty

A confidence interval may be considered analogous to some associated degree of uncertainty. Therefore, current and potentially reduced parameter uncertainty can be described in terms of the commonly used 95% confidence interval. There are two ways to obtain these confidence intervals depending on what type of parameter is being evaluated. For sampling parameters, these intervals can be measured using the original sample data; this is explained in detail in Chapter 4. For non-sampling parameters, the intervals can be estimated using professional judgment since there is no such data available; a detailed explanation is provided in Chapter 5. The size of the current 95% confidence interval is presumed for the hypothetical simulations in this chapter.

3.5 The Timber Supply Model

Timber supply models are used here to conduct sensitivity analyses, and examine effects of mistakes in projected volume on AAC by simulating differing projections of

timber supply over time given current and reduced levels of uncertainty¹⁰. The benefits of reduced uncertainty are compared in terms of NPVs of timber supply streams. Since timber supply is used to examine the effects of uncertainty, there is an opportunity to investigate factors that may influence the value of timber supply patterns and the subsequent benefits from reducing uncertainty. The factors examined here include existing age-class structures, total harvest volume, interest rates, sustained yield constraints and capital cost implications of varying harvest levels.

The modeling procedure and results of simulations are presented in five sequential models, each of which adds a further degree of complexity to the analysis. A sequential approach simplifies the overall explanation, and it exposes some of the conditions that are key in influencing the benefits of information collection. Model 1 serves to lay the foundation for the modeling process and optimizes for a maximum even-flow harvest. It examines how correcting mistakes in AAC, which are due to uncertainties in growth and yield estimates, affect total harvest volume.

Model 2 expands on Model 1 by reducing the uncertainty in growth and yield estimates, instead of eliminating it. This model optimizes for maximum NPV under even-flow constraints using a 0% interest rate. Model 3 introduces a 6% interest rate. Model 4 ventures away from even-flow constraints and examines sustained yield constraints under differing levels of flexibility; both 0% and 6% interest rates are

¹⁰ The simulations draw on methods from similar analyses by Eid (2000), the BC Forest Service (1999) and van Kooten et al (1992).

employed.¹¹ Model 5 returns to even-flow constraints and incorporates a cost function to reflect capital constraints in a forest products mill.

The timber supply models are constructed using the Woodstock Forest Modeling System (version 2.5) and the linear programming solver XA. The models are run as Monte Carlo simulations from MATLAB (version 6.1) using the MOSEK optimization toolbox (version 2). All models have a planning horizon of forty, five-year periods, or 200 years; this is a common planning horizon for Alberta forest products companies (Schneider, 2001).

Each hypothetical forest is deciduous-dominated mixedwood and consists of a single forest type (yield curve in Appendix A)¹². Only the deciduous component is modeled, using a clearcut harvest regime that regenerates naturally and without delay back to the original forest. Three different starting age-class structures are presented here (Figure 3-1). A mature forest structure is presented because it is applicable to Alberta, where much of the forested land base is comprised of mature trees. A juvenile structure is also presented in order to provide a range of starting conditions for more broadly applicable results. The mature and juvenile distributions are contrived, each serving to demonstrate one of many possible mature and juvenile age-class distributions.

¹¹ Interest rates of 0% and 6% were chosen because they are useful for modeling the preferences of two different bodies of interest. One body of interest to this project is the forest industry, who faces interest rates of at least 6%. The other is society, who typically has a discount rate less than industry. Luckert and Adamowicz (1993) provide a literature review of this issue.

¹² The yield curve applies to deciduous-dominated sites in both the upper and lower foothills natural subregion with medium site quality, C-density stands and 10% conifer. This yield table has been selected for the research project because, according to temporary sample plot data, it represents the most commonly occurring sites on the Weyerhaeuser Edson W6 forest management unit. Weyerhaeuser Company Ltd. provided the temporary sample plot data for the case study in Chapter 4.

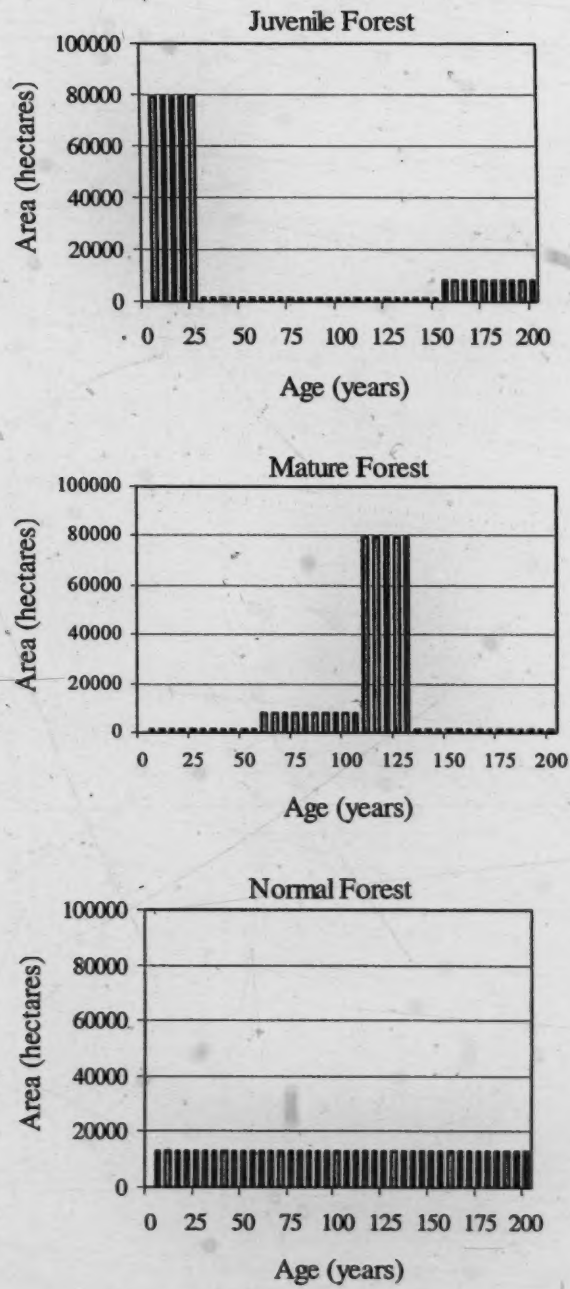


Figure 3-1 Three age-class distributions.

Finally, a structure with an equal representation of age-classes (from age 1 through 200) across the land base is presented. This simple structure is useful for uncovering basic processes without interference from skewed age-class distributions. For convenience, in the remainder of the thesis this forest shall be referred to as a "normal" forest, even though a true normal forest consists of an equal distribution of ages only up to the rotation age.

The forest is 516,990 hectares in size. This size was selected by working backward from the capacity of the Weyerhaeuser Company Ltd. Edson oriented strand board (OSB) mill that will be used in Model 5. The even-flow harvest from a mature forest of this area generates a volume of wood roughly equal to the mill capacity; 600,000m³/year.

3.6 Model Results

3.6.1 Model 1: Correcting Mistakes in AAC

This simplified model provides the opportunity to examine how existing age-class structures may be key in influencing the volume effects of uncertain harvest levels. It highlights some of the processes that drive the results in the subsequent models. A commonly used measure of uncertainty is the 95% confidence interval, which includes a range of values with a 95% probability of containing the parameter being estimated. In Model 1, the current 95% confidence interval around the mean growth and yield estimates is assumed to include values that vary by plus or minus 50% of the mean values. Forest practitioners probably would not know where they are within this level of uncertainty; that is, they would not know if they have over-estimated or under-estimated

growth and yield. Accordingly, they would not know if they are unknowingly over-cutting or under-cutting the forest relative to the true sustainable harvest level, or possibly even unknowingly cutting *at* the true sustainable harvest level.

To simulate this uncertainty at the forest level, three possible current harvest levels are modeled, each reflecting yield values from the two confidence limits and the middle of the assumed 95% interval. Imagine that after a period of 10 years new knowledge discloses the true growth and yield values. The AAC is recalculated at that time to reflect this discovery. The first of the paired subscripts in the following explanation indicates which time period the AAC applies to; the subscript '1' indicates the time period prior to obtaining the new information and the subscript '2' indicates the time period subsequent to obtaining the new information. The second of the paired subscripts describes the initial uncertainty; the subscript 'H' indicates a high harvest level resulting from growth and yield estimates in the upper bound of initial uncertainty, the subscript 'L' signifies the lower bound of initial uncertainty and the subscript 'M' signifies the middle. Figure 3-2 accompanies the following explanation.

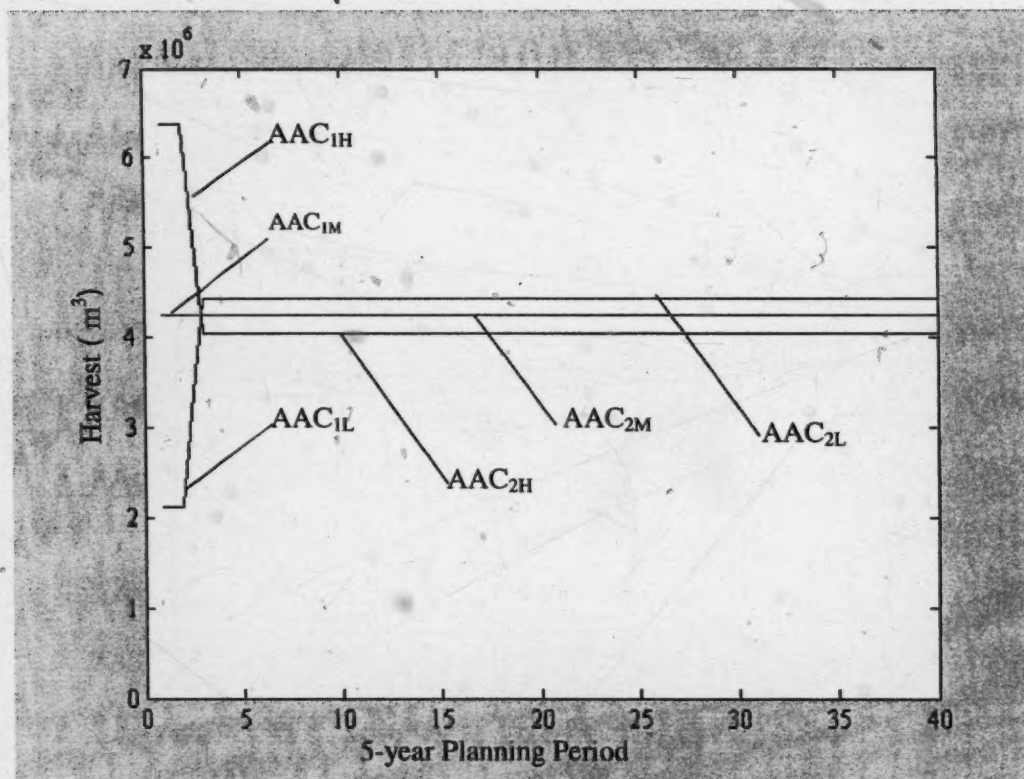


Figure 3-2 Harvest levels in normal forest according to initial AAC mistake.

The timber supply program is run to establish the even-flow AAC (AAC_{1M}) for 200 years. Then, to characterize the notion that, in reality, foresters would not know where they are relative to the truth in terms of estimated yield values, two additional AACs are created. AAC_{1H} is 50% above AAC_{1M}, and represents unknowingly over-cutting the forest as a result of uncertainty in growth and yield.¹³ AAC_{1L} is 50% below AAC_{1M}, and represents unknowingly under-cutting the forest as a result of uncertainty in growth and yield values. These three harvest levels occur for 10 years, after which new information is obtained that eliminates uncertainty, and the AAC is recalculated.

¹³ The uncertainty imposed on the AAC mirrors the uncertainty in growth and yield values. To check this parallel relationship, the AAC based on the "true" yield table was multiplied by a level of uncertainty. The product was compared to an AAC optimized based on a yield table of equivalent uncertainty. In the end, both AACs were equal.

When the AAC is recalculated, depending on whether the initial AAC was too high or too low, the harvest level adjusts to the new information by shifting either downwards or upwards. The initial cutting scenario and its effects on the structure of the forest cause these differing harvest levels in years 11 through 200. That is, the cut scenarios in years 1 through 10 create different starting conditions for the remaining years; unknowingly over-cutting creates a forest with subsequently less available timber and unknowingly under-cutting creates a forest with subsequently more available timber. In all three forests, an initial over-cut in years one through 10 results in a harvest level in the second time period (AAC_{2H}) lower than AAC_{1M} (Figure 3-2). Conversely, an initial under-cut results in a harvest level in the second time period (AAC_{2L}) higher than AAC_{1M} (Figure 3-2). An initial middle cut results in a harvest level (AAC_{2M}) equal to AAC_{1M} .

The model as currently presented provides an opportunity to examine how existing forest structure may be key in influencing the effects of uncertain harvest levels. Namely, is total harvest volume affected by mistakes in AAC that are subsequently corrected or is there a zero sum effect? The total volumes harvested over the 200-year planning horizon are summed to examine this possibility (Table 3-1).

Table 3-1 Comparison of total volumes harvested in Model 1.

Forest Type	Initial Harvest Scenario	AAC Years 1-10 (m3)	AAC Years 11-200 (m3)	Total Volume Harvested (m3)	% Difference From Constant AAC Total Volume
Normal	Overcut	6,375,434	4,036,635	166,143,011	0.977
	Constant AAC	4,250,289	4,250,289	170,011,576	1.000
	Undercut	2,125,145	4,428,528	172,534,354	1.015
Juvenile	Overcut	1,084,573	678,097	27,936,836	0.966
	Constant AAC	723,049	723,049	28,921,944	1.000
	Undercut	361,524	757,000	29,489,034	1.020
Mature	Overcut	4,500,100	2,961,647	121,542,795	1.013
	Constant AAC	3,000,067	3,000,067	120,002,663	1.000
	Undercut	1,500,033	2,905,260	113,399,944	0.945

These results demonstrate the importance of starting conditions. In the normal and juvenile under-cut forests there are almost zero-sum effects. That is, the harvest volume losses from initial under-cutting are moderated by the subsequently increased AACs, causing the total harvest volumes to be almost equal to those from the constant AACs. In the mature over-cut forest there is almost a zero-sum effect as well; the abundance of merchantable timber seems to act as a buffer against over-cutting mistakes.

In contrast, the normal and juvenile forests are more sensitive to initial over-cutting mistakes, and the mature forest is more sensitive to initial under-cutting mistakes. In the normal and juvenile forests, there is not enough existing merchantable timber to compensate for initial over-cutting. In the mature forest initial under-cutting causes a

reduction in total harvest volume, possibly due to the natural death of unharvested, over-mature timber.¹⁴

Some interesting deductions can be drawn from these results. For instance, over-cutting mistakes in mature forests are not very costly in terms of harvest volumes, implying that the dollar returns to reducing uncertainty may be low. Conversely, under-cutting mistakes in mature forests cause losses in volume implying that the dollar returns to reducing uncertainty could be higher. Opposite deductions can be drawn in the normal and juvenile forests.

3.6.2 Model 2: Introduce Reduced Uncertainty and Values

Model 2 builds upon Model 1 and compares the dollar benefits of reduced uncertainty in terms of NPVs. It models a situation where, after 10 years, new information is obtained that reduces the uncertainty in growth and yield, as opposed to eliminating it, as in Model 1. To simulate this situation, conceptualize two states of the world. In the first state of the world, there is some initial level of uncertainty in growth and yield. For example, the 95% confidence interval includes growth and yield estimates that vary by plus or minus 50% of the mean yield values, just as in Model 1. After 10 years, existing levels of information collection¹⁵ reduce this uncertainty so that the yield values vary normally within a plus or minus 30% range. In the second state of the world, there is the same level of initial uncertainty. After 10 years, *increased* investment in

¹⁴ Hardwood yield begins to decline linearly at age 125 so that volume equals zero by age 180. Therefore, it is possible that mature trees may be lost to natural death before the allowable cut level allows their harvest.

¹⁵ "Existing levels" of information collection refer to information obtained from status quo levels of research and sampling, and from observing management effects while working in the forest.

information collection reduces uncertainty so that the yield values vary normally within a plus or minus 10% range.

The two states of the world are modeled in the following manner. Recall the 200-year planning horizon in the timber supply model. During the initial 10-year period the model projects three different harvest levels. These three levels reflect the 50% uncertainty in the growth rate of the forest. That is, they characterize the notion that forest practitioners would not know where their growth and yield estimates lie relative to the truth. Therefore, a high yield estimate would result in unknowingly over-cutting, a low estimate would result in unknowingly under-cutting, and a middle estimate would result in unknowingly cutting at the sustainable AAC.

Then, for each of the three initial harvest levels, Monte Carlo simulations begin after 10 years. The model projects 200 different possible harvest levels that reflect reduced uncertainty in growth and yield, either 30% or 10%, according to the two states of the world. This phase of the model simulates possible outcomes that may be associated with the forest practitioners' decision regarding whether or not to invest in new information.

To explain how the 200 harvest levels are obtained for each simulation, consider the initial over-cut scenario. The AAC_{2H} (Figure 3-2) is multiplied 200 times by a normally-distributed random factor that reflects one of the two levels of reduced uncertainty. The random factors are generated using the following equation, where r is one of an array of 200 random numbers with elements normally distributed with a mean of 0, a variance of 1, and a standard deviation of 1.

$$\text{Random factor} = 1 + (\text{percent uncertainty}) * r$$

The result is a distribution of 200 AACs that vary by 30% or 10% around AAC_{2H} for years 11 through 200 (Figure 3-3).

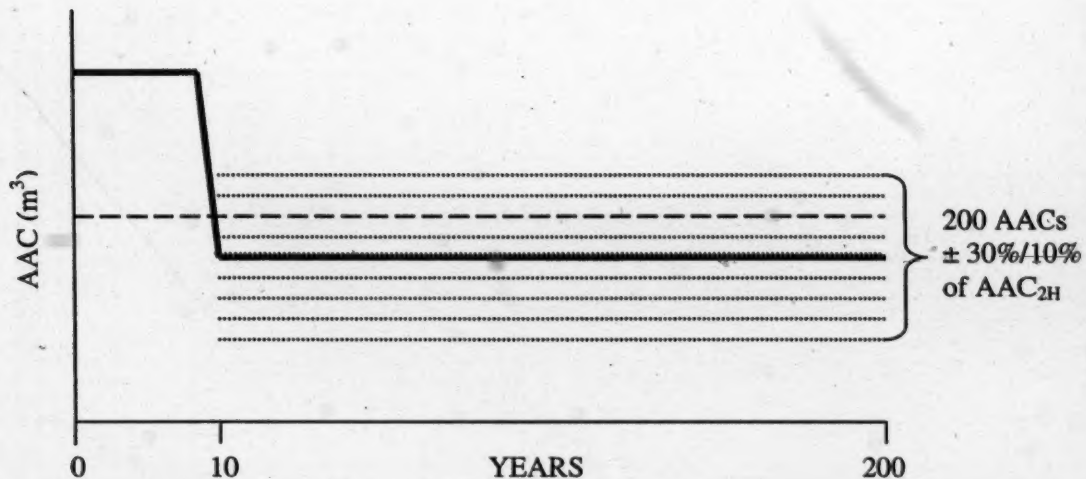


Figure 3-3 Distribution of erroneous AACs for years 11 through 200 following initial over-cutting.

It is important to note here that the yield values in the model represent the “true” growth rate of the forest, and are used in conjunction with the 200 erroneous AACs. However, these yield values may not necessarily support the erroneous AACs. That is, the true growth rate of the forest will not necessarily support the uncertain harvest levels. This situation opens up the possibility for projected timber supply crashes in instances where the AAC is manipulated to a level that is too high for the forest to support (i.e. over-cutting). That is, if growth and yield is still over-estimated with the new information, over-cutting may still occur and the timber supply model will project an exhaustion of merchantable timber supply at some time during the planning horizon.

Therefore, considering the possibility of projected supply crashes, a more appropriate depiction of Figure 3-3 is shown in Figure 3-4. Supply crashes occur where the uncertain AAC, for years 11 through 200, is higher than AAC_{2H} , causing the forest to be depleted of merchantable volume. The higher the uncertain AAC, the sooner the crash occurs.¹⁶

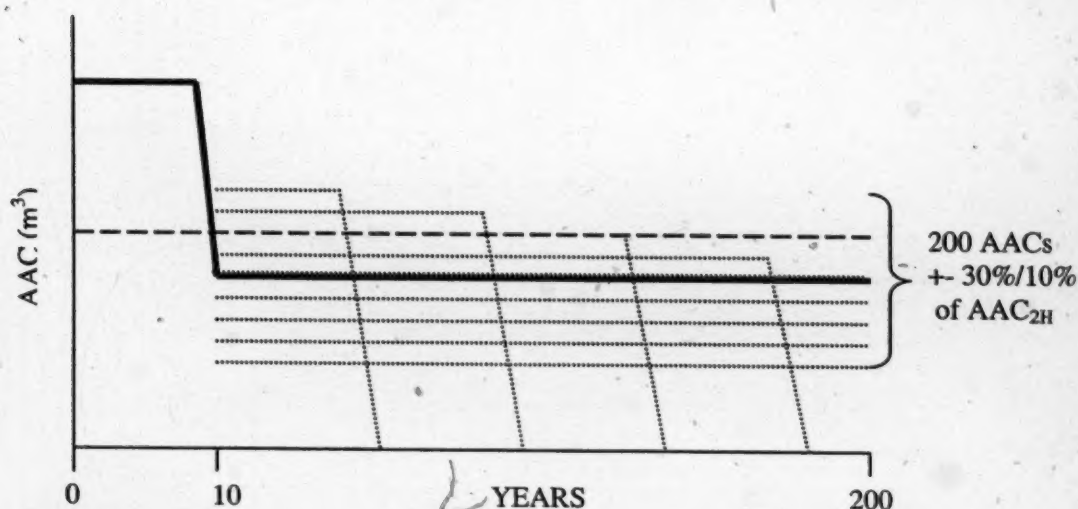


Figure 3-4 Distribution of erroneous AACs for years 11 through 200, including unsustainable AACs.

¹⁶ In reality, it is unlikely a supply crash would actually occur since forest practitioners would probably observe a discrepancy between growth rates and harvest levels long before a timber shortage happened. To model a more realistic situation without supply crashes would involve several additional influxes of information. With each influx the AAC would be recalculated. Therefore, harvest levels higher than AAC_{2H} would exhibit a stepwise decline instead of simply crashing. This method would reduce the value of information collection compared to the present method with supply crashes because increased information would delay or prevent crashes. The avoidance or delay of timber supply crashes drives the benefits of uncertainty reduction in the present model; this becomes apparent in the Model 2 results. For the purposes of the framework presented here, a model with supply crashes is useful because it more clearly exposes trends associated with harvesting mistakes.

Dollar values of timber supply streams are introduced within the sensitivity analyses in Model 2. The model optimizes for maximum NPV¹⁷ using a \$5/m³ stumpage value¹⁸ and a 0% discount rate. With 200 simulations, three levels of initial uncertainty, and two levels of reduced uncertainty, there are a total of 1200 timber supply runs to evaluate for each of the three age-class structures.

This modeling process can be put into the context of the economic value of information. According to economic theory, the expected value of information depends upon prior knowledge, research opportunities that can refine the prior knowledge, available decision options, and expected gains (Hammitt and Shlyakhter, 1999). Decision trees are often used to map the probabilities of making different decisions according to how much new information is obtained. They are used to estimate the expected value of information. Figure 3-5 is a decision tree that summarizes the modeling process for the framework presented here.

¹⁷ This is a simplifying assumption; a forest products mill would probably optimize to minimize costs, not maximize profit (M. Messmer, Timber Supply Manager, Weyerhaeuser Company Limited, Edmonton, Alberta, personal communication, July 2002).

¹⁸ This value was used by Hegan and Luckert (2000).

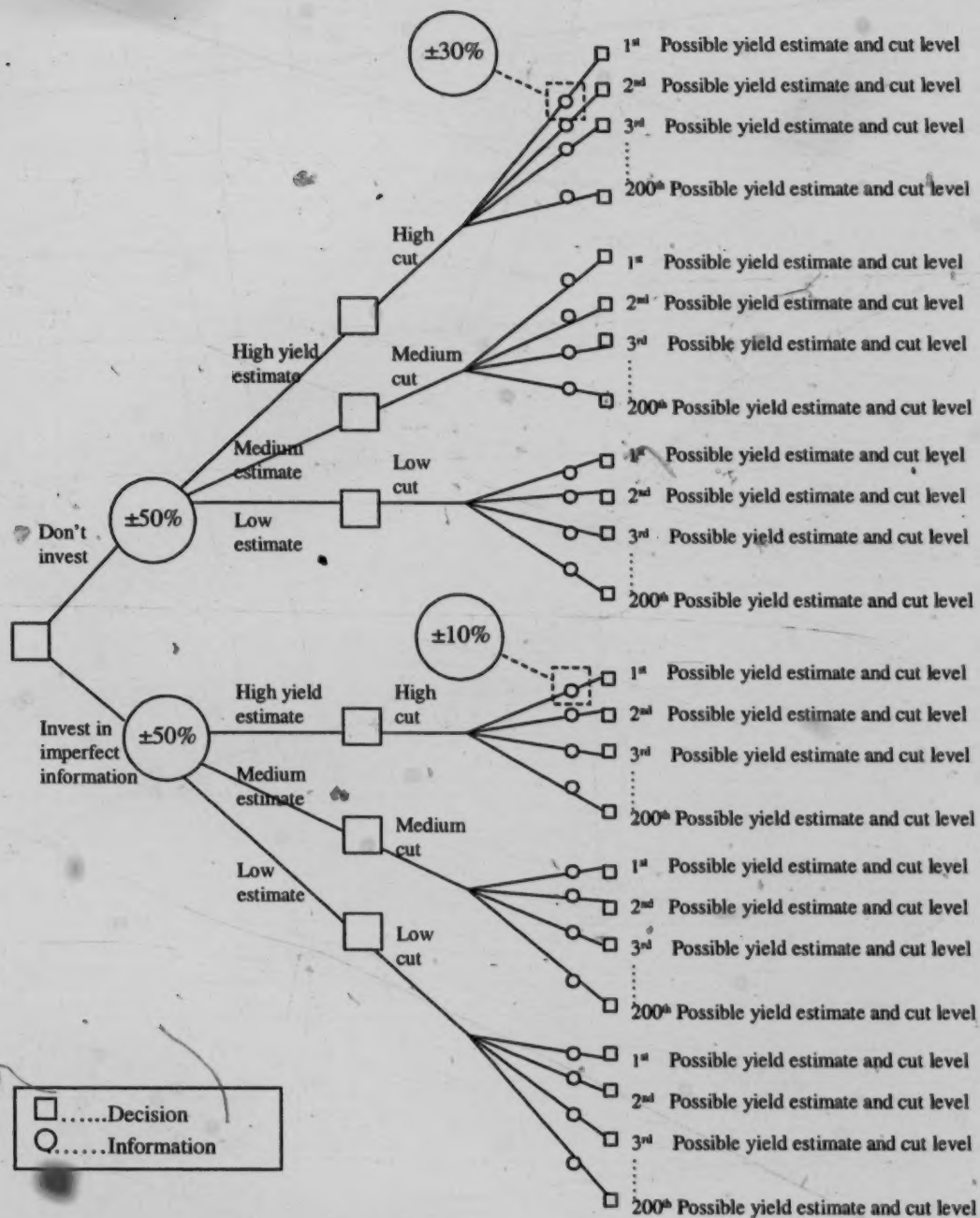


Figure 3-5 Decision tree of harvest choices.

Figure 3-5 also clarifies how the dollar benefits from reducing uncertainty, as estimated in this framework, are different from the "economic value of information"; this difference was alluded to in the beginning of Chapter 2. Recall that the economic value of information, as discussed by Hammitt and Shlyakhter (1999), depends partially on "the probability that improved information will result in a different decision and the magnitude of the resulting gain, and... the extent to which uncertainty about the parameter contributes to uncertainty about which decision option is preferred." In this framework, however, the only true decision occurs at the beginning of the decision tree, and that is whether or not to invest in increased information. In the rest of the decision tree, projected volume information rules the harvest levels instead of influencing harvest-level decisions. This difference is partly owing to Alberta policy constraints, whereby volume predictions play a large role in determining AACs. In this sense, one might view the framework presented here as a *constrained* value of information problem.

Modeling the unconstrained value of information would be far more complex and is therefore not pursued here. However, the framework as currently presented is a useful tool for assisting with investment decisions and exposing key factors that drive the benefits of reducing uncertainty. It also provides a constructive foundation for more complex analyses.

The results from Model 2 are presented in Table 3-2. All increases in harvest volumes and NPVs are shown to be significantly greater than zero at the 5% level. These results are discussed in the paragraphs that follow.

Table 3-2 Model 2 results; even-flow constraints and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 479,893,940	95,978,784	57	92	\$ 559,280,550	111,856,110	68	92	15,877,326	\$ 79,386,612	0.535
	Middle	\$ 482,792,570	96,558,510	58	92	\$ 565,541,060	113,108,210	69	92	16,549,700	\$ 82,748,494	0.535
	Under-cut	\$ 482,576,610	96,515,318	59	92	\$ 567,463,240	113,492,640	69	92	16,977,322	\$ 84,886,625	0.535
Juvenile	Over-cut	\$ 75,250,912	15,050,182	42	92	\$ 87,338,822	17,467,764	48	92	2,417,582	\$ 12,087,910	0.535
	Middle	\$ 76,181,305	15,236,260	42	92	\$ 88,955,320	17,791,063	48	92	2,554,803	\$ 12,774,015	0.535
	Under-cut	\$ 75,983,342	15,196,668	43	92	\$ 89,240,881	17,848,176	48	92	2,651,508	\$ 13,257,539	0.535
Mature	Over-cut	\$ 375,111,940	75,022,385	71	92	\$ 418,670,850	83,734,168	75	92	8,711,783	\$ 43,558,913	0.845
	Middle	\$ 364,568,830	72,913,763	71	92	\$ 408,517,870	81,703,571	75	92	8,789,808	\$ 43,949,042	0.845
	Under-cut	\$ 343,282,360	68,656,470	74	92	\$ 387,231,040	77,446,205	79	92	8,789,735	\$ 43,948,677	0.845

In the juvenile forest, there is a scarcity of existing merchantable timber and this causes lower harvest levels and earlier supply crashes than in the other scenarios. The over-all values of timber supply streams are therefore relatively small. Reducing uncertainty postpones the crashes by an average of six years, which increases the total harvest volumes causing significant increases in mean NPVs (hereafter referred to as "benefits").

In the mature forest there is an abundance of merchantable timber and this causes higher harvest levels and later supply crashes. The over-all values of the timber supply streams are therefore larger than in the juvenile forest. Reducing uncertainty postpones the crashes by an average of four years, less so than in the juvenile forest but enough that the benefits are significantly higher.

Finally, because timber supply in the normal forest is distributed evenly across all age-classes, the normal forest lends itself well to the even-flow harvest regime. The over-all values are therefore highest, despite the fact that the average timing of the supply crashes is midpoint between the juvenile and mature forests. Reducing uncertainty postpones the crashes by an average of 10 years, more so than the other two forests, resulting in the largest benefits.

The level of increase in the NPV is not very informative for making a decision about whether to invest in information. Therefore, in addition to looking at significant differences, a cumulative probability distribution (CPD) associated with increased information can be used to estimate the probability that the NPV of a timber supply stream based on increased information will be higher than the cost of obtaining that information. Since the costs of investing in increased information are not incorporated in

this project, the mean NPV without increased information is used instead of costs for a baseline comparison. Therefore, Table 3-2 also presents the probability that the NPV associated with increased information will be higher than the mean NPV without increased information. Figure 3-6 shows the CPD for the over-cut scenario in the normal forest. The distribution for all other scenarios in Model 2 have a similar shape and are therefore not included here. The probability that the NPV will increase to a value higher than the mean NPV before uncertainty is reduced is 0.535 for the normal and juvenile forests and 0.845 for the mature forest.

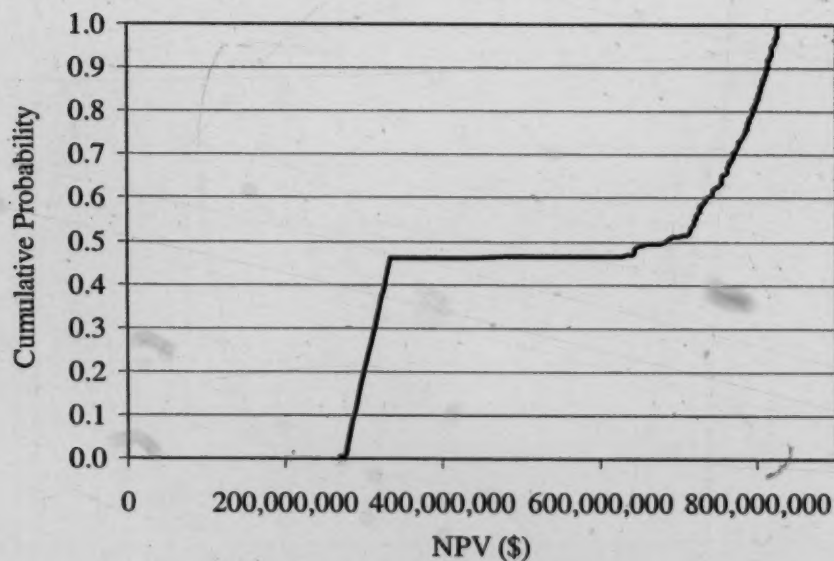


Figure 3-6 Cumulative probability distribution of NPVs; normal forest, even-flow constraints, 0% interest rate and initial over-cutting.

3.6.3 Model 3: Introduce 6% Interest Rate

Interest rates may influence the value of timber supply patterns. Therefore, so sensitivity analysis is done by adding a 6% rate, a rate which may characterize the cost of capital that industry faces. Table 3-3 summarizes the results from Model 3. The CPD for NPVs in the normal over-cut forest with uncertainty reduced to 10% is shown in Figure 3-7. The distributions for all other scenarios have a similar shape and are not included here.

Table 3-3 Model 3 results; even-flow constraints and 6% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPV's	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m³)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 72,197,452	95,978,784	57	92	\$ 73,968,165	111,856,110	68	92	15,877,326	\$ 1,770,713	0.775
	Middle	\$ 60,045,567	96,558,509	58	92	\$ 61,833,280	113,108,210	69	92	16,549,701	\$ 1,787,713	0.765
	Under-cut	\$ 47,649,698	96,515,317	59	92	\$ 49,417,143	113,492,640	69	92	16,977,323	\$ 1,767,445	0.750
Juvenile	Over-cut	\$ 11,936,646	15,050,182	42	92	\$ 12,302,138	17,467,764	48	92	2,417,582	\$ 365,492	0.885
	Middle	\$ 9,924,745	15,236,260	42	92	\$ 10,298,075	17,791,063	48	92	2,554,803	\$ 373,330	0.870
	Under-cut	\$ 7,828,457	15,196,668	43	92	\$ 8,203,711	17,848,175	48	92	2,651,507	\$ 375,254	0.860
Mature	Over-cut	\$ 52,617,287	75,022,385	71	92	\$ 53,282,529	83,734,167	75	92	8,711,782	\$ 665,243	0.665
	Middle	\$ 43,128,353	72,913,762	71	92	\$ 43,800,013	81,703,570	75	92	8,789,808	\$ 671,660	0.665
	Under-cut	\$ 32,640,833	68,656,470	74	92	\$ 33,290,542	77,446,205	79	92	8,789,735	\$ 649,709	0.665

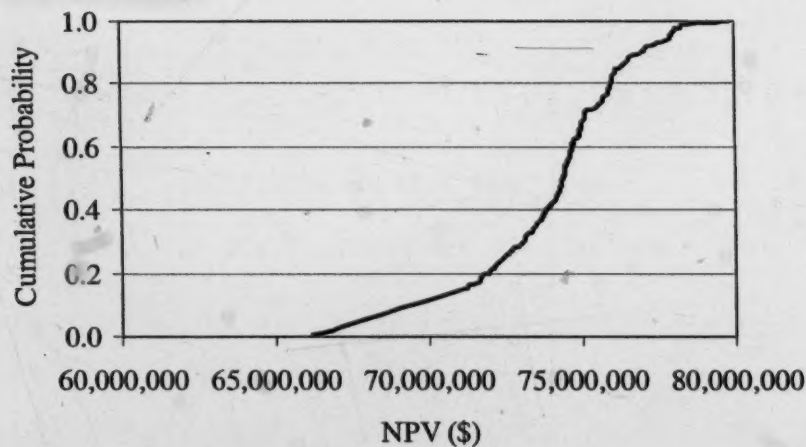


Figure 3-7 Cumulative probability distribution of NPVs; normal forest, even-flow constraints, 6% interest rate and initial over-cutting.

The 6% interest rate affects the benefits of uncertainty reduction in several ways. To begin, although the sizes of the timber supply streams are the same, the benefits of uncertainty reduction are significantly smaller because they are discounted by 6%. This discounting has a notable effect in the mature forest where the benefits from reducing uncertainty are now insignificant. The probability of the NPV increasing above the previous mean in the mature forest is 0.665. The benefits in the normal and juvenile forests are still significant, and the probabilities are in the range of 0.7 and 0.8.

3.6.4 Model 4: Relax Sustained Yield Constraints

Sustained yield constraints may influence the value of timber supply patterns and the subsequent benefits from reducing uncertainty. Examining this influence may also provide insight into how priorities regarding information collection might change with variations in cut-control policy.

This project examines two of the policy scenarios used by Hegan and Luckert (2000) in their economic assessment of the allowable cut effect. The first policy scenario mimics the estimated, current cut control policy for Alberta forest management agreements (FMAs), which allows for a degree of harvest flexibility within the sustained yield constraints (Hegan and Luckert, 2000). To model this scenario, annual harvests are permitted to be within $\pm 25\%$ of the even-flow AAC¹⁹, 5-year harvest totals must be within $\pm 10\%$ of the 5-year allowable cut, and 10-year harvest totals must coincide with the total 10-year allowable cut (Hegan and Luckert, 2000). The second policy scenario models twice flexibility around the sustainable AAC by doubling the parameters from the current policy scenario and requiring convergence every twenty years. Table 3-4 through Table 3-7 show the NPVs and harvest volumes, and effects from reducing uncertainty, under the two policy scenarios and both interest rates. The CPDs for the 0% scenarios are similar in shape to Figure 3-6, and the distributions for the 6% scenarios are similar in shape to Figure 3-7.

¹⁹ The annual flexibility constraints are implicitly assumed since 5-year periods are used.

Table 3-4 Model 4 results; current flexibility and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 481,766,340	96,353,264	57	92	\$ 563,628,820	112,725,760	68	91	16,372,496	\$ 81,862,476	0.540
	Middle	\$ 485,488,380	97,097,673	59	92	\$ 570,265,250	114,033,050	69	91	16,955,377	\$ 84,776,866	0.540
	Under-cut	\$ 484,795,000	96,938,995	59	92	\$ 574,617,200	114,923,440	69	90	17,964,445	\$ 89,822,207	0.540
Juvenile	Over-cut	\$ 77,844,116	15,568,822	42	88	\$ 93,442,350	18,688,469	48	81	3,119,647	\$ 15,598,235	0.590
	Middle	\$ 78,826,865	15,765,372	43	88	\$ 96,346,699	19,269,339	48	79	3,503,967	\$ 17,519,834	0.600
	Under-cut	\$ 78,659,369	15,731,873	43	88	\$ 98,036,577	19,607,315	48	77	3,875,442	\$ 19,377,208	0.610
Mature	Over-cut	\$ 378,493,460	75,698,689	71	91	\$ 432,714,350	86,542,867	75	85	10,844,178	\$ 54,220,895	0.570
	Middle	\$ 367,890,790	73,578,156	72	91	\$ 422,726,050	84,545,206	75	85	10,967,050	\$ 54,812,252	0.570
	Under-cut	\$ 346,469,620	69,293,921	74	91	\$ 400,075,960	80,015,188	79	85	10,721,267	\$ 53,606,336	0.570

Table 3-5 Model 4 results; twice flexibility and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 509,359,700	101,871,940	57	82	\$ 633,276,870	126,655,370	67	63	24,783,430	\$ 123,917,170	0.680
	Middle	\$ 522,117,950	104,423,590	59	81	\$ 658,508,020	131,701,600	68	60	27,278,010	\$ 136,390,070	0.695
	Under-cut	\$ 524,961,090	104,992,210	60	81	\$ 667,111,610	133,422,320	69	60	28,430,110	\$ 142,150,520	0.695
Juvenile	Over-cut	\$ 80,550,812	16,110,162	43	82	\$ 101,340,940	20,268,188	47	63	4,158,026	\$ 20,790,133	0.680
	Middle	\$ 83,432,903	16,686,580	44	81	\$ 107,033,330	21,406,666	48	60	4,720,086	\$ 23,600,432	0.695
	Under-cut	\$ 84,047,214	16,809,442	44	81	\$ 108,978,570	21,795,713	48	60	4,986,271	\$ 24,931,357	0.695
Mature	Over-cut	\$ 445,853,560	89,170,709	71	62	\$ 562,710,170	112,542,030	75	23	23,371,321	\$ 116,856,600	0.880
	Middle	\$ 438,423,510	87,684,699	71	60	\$ 556,931,280	111,386,250	75	21	23,701,551	\$ 118,507,770	0.890
	Under-cut	\$ 377,464,910	75,492,978	76	83	\$ 455,998,880	91,199,772	82	65	15,706,794	\$ 78,533,972	0.670

Table 3-6 Model 4 results; current flexibility and 6% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%			Uncertainty Reduced to 10%			Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	
Normal	Over-cut	\$ 73,329,613	96,344,744	57	92	\$ 75,094,992	112,717,940	68	91	\$ 1,765,378
	Middle	\$ 61,031,762	97,089,541	59	92	\$ 62,787,446	114,044,720	69	91	\$ 1,755,684
	Under-cut	\$ 48,415,183	96,951,882	59	92	\$ 50,176,635	114,916,360	69	90	\$ 1,761,452
Juvenile	Over-cut	\$ 12,165,017	15,568,156	42	88	\$ 12,540,109	18,688,066	48	81	\$ 3,119,910
	Middle	\$ 10,118,693	15,764,834	43	88	\$ 10,503,270	19,269,192	48	79	\$ 3,504,358
	Under-cut	\$ 7,985,541	15,731,420	43	88	\$ 8,380,934	19,607,252	48	77	\$ 3,875,832
Mature	Over-cut	\$ 53,405,612	75,698,688	71	91	\$ 54,088,861	86,542,867	75	85	\$ 10,844,179
	Middle	\$ 43,777,004	73,578,156	72	91	\$ 44,467,991	84,545,205	75	85	\$ 10,967,049
	Under-cut	\$ 33,127,421	69,293,921	74	91	\$ 33,787,784	80,015,188	79	85	\$ 10,721,267

Table 3-7 Model 4 results; twice flexibility and 6% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%			Uncertainty Reduced to 10%			Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	
Normal	Over-cut	\$ 81,063,584	101,736,260	57	82	\$ 82,947,815	126,539,250	67	63	\$ 1,884,231
	Middle	\$ 66,964,331	104,309,990	59	81	\$ 68,782,332	131,618,360	68	60	\$ 1,818,001
	Under-cut	\$ 52,315,185	104,881,130	60	81	\$ 54,093,989	133,337,050	69	60	\$ 1,778,804
Juvenile	Over-cut	\$ 13,452,946	16,101,066	43	82	\$ 13,844,703	20,263,399	47	63	\$ 4,162,333
	Middle	\$ 11,126,459	16,680,865	44	81	\$ 11,533,297	21,404,134	48	60	\$ 4,723,269
	Under-cut	\$ 8,660,537	16,804,549	44	81	\$ 9,079,115	21,793,590	48	60	\$ 4,989,041
Mature	Over-cut	\$ 59,753,135	89,170,847	71	62	\$ 60,519,489	112,542,150	75	23	\$ 23,371,303
	Middle	\$ 48,399,750	87,684,800	71	60	\$ 49,175,079	111,396,340	75	21	\$ 23,701,540
	Under-cut	\$ 36,520,054	75,493,258	76	83	\$ 37,248,584	91,200,090	82	65	\$ 15,706,832

Relaxing the stringency of sustained yield constraints has several effects on the values of timber supply streams. Compared to the even-flow scenarios, the size and value of the timber supply streams in Model 4 are larger²⁰ because flexibility results in fewer supply crashes. Harvests are more opportunistic under flexibility; they can take advantage of supply peaks without compromising harvest obligations during future troughs.

As sustained yield constraints are relaxed, there are larger benefits to reducing uncertainty because the number of supply crashes is generally reduced²¹; recall that under even-flow constraints the number of crashes remained constant. Furthermore, similar to the even-flow simulations, reducing uncertainty creates significant benefits in all scenarios except in the mature forest with values discounted using a 6% interest rate. Finally, there is at least a 0.5 probability in all scenarios that the NPV will increase to a value higher than the mean NPV before uncertainty reduction.

3.6.5 Model 5: Introduce Cost Function

Until now, this study has examined the potential benefits of uncertainty reduction from a woodlands perspective; now it will take an integrated firm's perspective. Vertical integration in the forest products industry is incorporated by examining the cost implications of varying harvest levels as they apply to the capital constraints in the mill.

²⁰ These increases were checked for significance. The current flexibility causes significant increases in the values of timber supply streams in the following scenarios: the juvenile over-cut scenario under a 6% interest rate with uncertainty reduced to 30%; all forests under a 6% interest rate with uncertainty reduced to 10%. The twice flexibility causes significant increases in all scenarios except values in the normal and juvenile forests under 0% interest rate with uncertainty reduced to 30%, and volumes and values in the normal and juvenile forests under both interest rates with uncertainty reduced to 30%.

²¹ An exception occurs in the normal forest, where current flexibility causes an increase in volume benefits yet a decrease in positively-discounted value benefits. This may be because the volume benefits accrue later in the planning horizon and are heavily discounted. In any case, the difference is very small.

The cost implications of capital constraints may further influence the value of different timber supply patterns. Capital costs are only one aspect of the total costs that may be associated with deviations in harvest levels.²² Therefore, the simulation results in this section should be viewed in relative, rather than absolute, terms; it is the trends that are of importance.

The cost implications of capital constraints have been examined in previous studies and suggest increasing costs associated with deviations in harvest levels. A report to the BC Ministry of Forests Forest Practices Branch by Venture Forestry Consulting Inc. states that fixed costs per cubic meter will increase with reductions in AAC (Venture Forestry Consulting Inc., 2000). It also states that "harvesting equipment is operated most cost effectively when optimum yearly volumes are allocated... achieving these optimum levels is more difficult with a reduced AAC". Furthermore, Metzger (1998) found that long-term reductions in timber supply in Oregon could result in temporary mill shutdowns, making it more difficult to bear fixed costs and to invest in technological improvements.

²² Additional cost implications of varying harvest levels may stem from macro-economic, ecological, silvicultural and operations constraints. First, macro-economic costs associated with reduced harvest levels can be measured by changes in such measures as employment, income, capital, gross domestic product, stumpage, or output. Reductions in timber supply could result in temporary mill shutdowns, and these shutdowns, especially in forest-dependent communities, could result in "increased dependence on social support and skilled workers leaving the region" (Metzger, 1998). "This in turn could result in reduced consumer spending and local taxes, and other services could also be affected" (Metzger, 1998). The degree of these effects would depend on the diversity of the communities' economic base (Hardy Stevenson and Associates, 1996). In general, these findings imply increasing costs associated with negative deviations in AAC. Secondly, ecological costs associated with increased or decreased harvest levels are ambiguous and very difficult to quantify. The costs associated with risk of fire, habitat, biodiversity, soil, nutrient levels, watersheds and other ecological factors, depend upon the perspective from which they are viewed. Therefore, costs could be either increasing or decreasing with positive and negative deviations in AAC. Finally, changes in harvest levels may affect silviculture and operations costs. Deviations in AAC could change costs associated with road building, harvesting and regeneration either upward or downward.

In this study, the capital cost implications of varying harvest levels are initially examined by estimating how capital costs are a function of harvest level. Quantifying the size, shape and slope of the cost function is important to this analysis since it will affect the values of different timber supply patterns. The size, shape and slope will depend on the type of log market being considered. Consider, first, a long-run situation where the presence of log markets balances log surpluses and shortages and capital is perfectly mobile. Assume that the cost function can be represented on a graph with positive and negative deviations from the current harvest level shown on the x axis by varying degrees of 'increased' and 'decreased' harvests relative to the 'current harvest'. Therefore, in a simplified long-run case one might assume a horizontal cost function, since capital is not constraining (Figure 3-8).

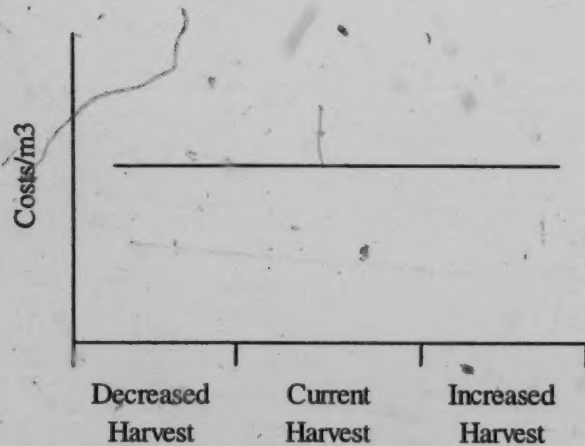


Figure 3-8 Long-run cost function.

Now consider a short-run situation where there is an absence of log markets and a lack of capital mobility, so that the cost burden of log surpluses and shortages must be

endured by the mill. To incorporate short-run costs that are proportional to deviations from the initial AAC that the mill was built for, a revised cost function could take on a symmetrical V-shape (Figure 3-9).²³

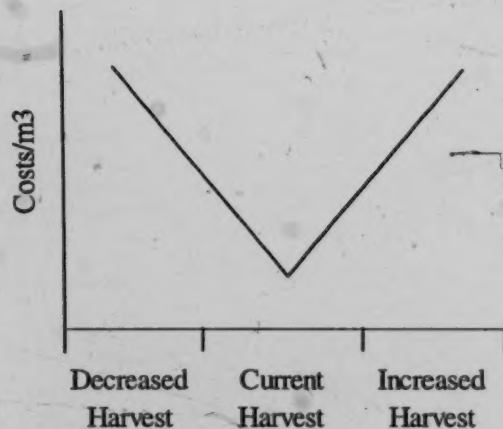


Figure 3-9 Short-run cost function.

Finally, consider an intermediate run of three to 15 years, during which existing capital is fixed but new capital can enter.²⁴ An intermediate time frame is more relevant to this project because the five-year planning periods in the timber supply model prohibit a short-run approach, and analyzing potential benefits from uncertainty reduction is less relevant to a long-run approach. In the case of decreasing capacity utilization in the intermediate run, marginal fixed costs would increase per unit of wood input. In the case

²³ In the very short run, there may be cost savings associated with log surpluses as the mill may temporarily run at extra capacity by incorporating overtime hours or additional shifts (M. Messmer, Timber Supply Manager, Weyerhaeuser Company Limited, Edmonton, Alberta, personal communication, July 2002). These savings would not be sustainable over long periods and therefore are not applicable to this project, which utilizes modeling periods of five years.

²⁴ Boyd and Hyde (1989) suggest an intermediate run of three to fifteen years during which existing capital is fixed but new capital can enter.

of increasing capacity utilization, however, the opportunity for new capital to enter would ease costs otherwise associated with increased capacity utilization. These cost trends are now quantified; assume an initial capital investment of \$61,800,000²⁵ borrowed at 6% over a mill life of 20 years²⁶. The cost function now takes on an L-shape (Figure 3-10). Since these costs are fixed they increase per cubic meter as the mill capacity decreases. Depreciation is simplified so that the mill is completely functional until its twentieth year, at which time the capital requires replacement.

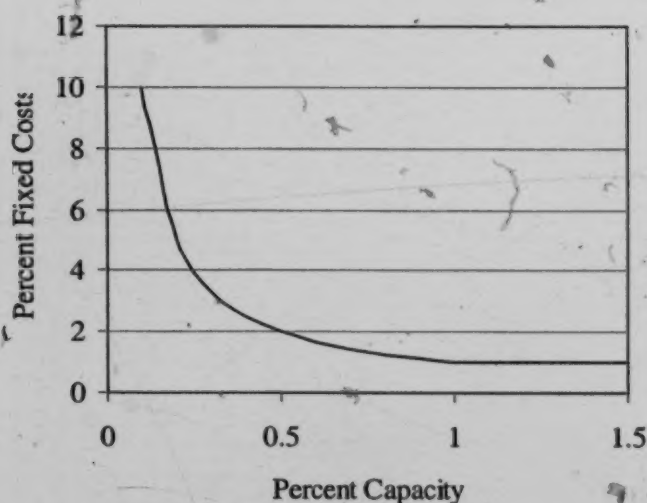


Figure 3-10 Intermediate-run cost function for different mill capacities.

On the left side of the intermediate-run cost function, reductions in harvest result in increasing mill costs owing to the under-utilized capital. The right side is somewhat more difficult to quantify since increases in harvest necessitate mill expansion, which

²⁵ This initial capital investment cost is equal to the estimated total construction costs for the Weyerhaeuser Company Ltd. Edson OSB mill. Since this figure was not available for the Edson mill, the initial capital investment costs, per cubic meter, were averaged for three oriented strand board mills in Alberta and Saskatchewan. This average was multiplied by the cubic meter output of the Edson mill.

²⁶ Trelawny (1997) suggests an average service life for structures is 22 years. A service life of 20 years is used here because the timber supply model is limited by the 5-year planning periods.

would simply shift the 100% capacity position on the chart to the right. Therefore, the right side of the cost function may be horizontal. This cost function is the same for mills of differing capacities since the costs and utilization levels are percentages, and it can therefore be used for all three initial harvest scenario simulations.

The simulations in this section optimize for a maximum NPV under even-flow sustained yield constraints using a 6% discount rate. Although it might be useful, flexibility constraints are not considered here. To do so would require joint optimizations since the cost function would need to be applied not only for deviations in AAC, but also for deviations in harvest as a result of flexibility around the AAC. Joint optimizations are beyond the scope of this project, however subsequent applications of the framework may endeavor to do this:

The cost function is applied within the timber supply simulations as follows. If there was a constant AAC throughout the planning horizon, every 20 years the existing capital would be exhausted and a new 20-year loan would be taken at a 6% interest rate to replace that capital. However, in these sensitivity analyses, the AAC changes in year 11, which in turn changes the capital investments according to whether the AAC increases or decreases. Consider, for example, that uncertainty reduction in year 11 causes an increase in AAC from $150,000\text{m}^3$ to $200,000\text{m}^3$. Given that the mill was built to sustain only $150,000\text{m}^3$, new capital must be brought in to accommodate the additional $50,000\text{m}^3$ of fiber. Recall this is the intermediate run, during which new capital can enter. Furthermore, whereas a short-run approach could use additional shifts and/or run above capacity to process the additional fiber, a three- to 15-year time frame is probably

too long for such measures to be feasible. Therefore, in year 11 there is a new capital investment, and this new capital will also have to be replaced every 20 years.

Now consider, for example, that in year 11 uncertainty reduction causes a decrease in AAC from $150,000\text{m}^3$ to $100,000\text{m}^3$. Given that the mill was built to sustain an AAC of $150,000\text{m}^3$ and the mill life is 20 years, the mill must operate at 66% capacity until year 20, at which time the capital can be replaced on a smaller scale that will accommodate the lower AAC. Recall that in the intermediate run existing capital is fixed. During the 10 years that the mill must operate below capacity, the left-hand side of the cost function is applied, and fixed costs per cubic meter are higher than they were in the first ten years when the mill operated at 100% capacity. At year 20, a new loan is taken and only enough capital is replaced to sustain $100,000\text{m}^3$; from then on fixed costs per cubic meter are 100% again.

The simulations in the previous models, that took a woodlands perspective, used stumpage values to derive NPVs. Now that the model uses a firm's perspective and considers cost implications of capital constraints, the product price of OSB is more appropriate to derive NPVs; the price used here $\$146.25/\text{m}^3$.²⁷ Accordingly, the results of these simulations are not comparable to the previous ones that use stumpage values to derive NPVs. It would be useful to compare the effects of uncertainty reduction in a situation where capital can enter but cannot leave, to the effects of uncertainty reduction where capital is perfectly mobile, which was assumed in the previous four models. To create such a baseline scenario, the 6% even-flow model (Model 3) is re-run using product price instead of stumpage value to calculate NPVs, and using a flat cost

²⁷ This is the average price of OSB per cubic meter input for the period April 1, 2001 to April 30, 2001, taken from Alberta Sustainable Resource Development (2001).

function.²⁸ The results from scenarios using the flat cost function are presented in Table 3-8 and the results from scenarios using the L-shaped cost function are presented in Table 3-9. The CPDs are similar in shape to Figure 3-7.

²⁸ A 0% interest rate is not used in these cost simulations since the loans are inferred at a positive interest rate.

Table 3-8 Model 5 results; long-run, flat cost function and even-flow constraints.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$1,812,642,900	95,978,784	57	92	\$1,861,531,300	111,856,110	68	92	15,877,326	\$48,888,379	0.785
	Middle	\$1,506,472,100	96,558,509	58	92	\$1,555,704,000	113,108,210	69	92	16,549,701	\$49,231,864	0.775
	Under-cut	\$1,194,310,500	96,515,318	59	92	\$1,242,821,300	113,492,640	69	92	16,977,322	\$48,510,761	0.765
Juvenile	Over-cut	\$298,537,580	15,050,182	42	92	\$308,740,240	17,467,764	48	92	2,417,582	\$10,202,654	0.925
	Middle	\$247,793,110	15,236,261	42	92	\$258,192,680	17,791,064	48	92	2,554,803	\$10,399,570	0.905
	Under-cut	\$194,936,190	15,196,668	43	92	\$205,367,580	17,848,175	48	92	2,651,507	\$10,431,390	0.890
Mature	Over-cut	\$1,324,277,200	75,022,385	71	92	\$1,341,604,200	83,734,167	75	92	8,711,782	\$17,326,991	0.665
	Middle	\$1,085,140,200	72,913,763	71	92	\$1,102,627,200	81,703,571	75	92	8,789,808	\$17,487,044	0.665
	Under-cut	\$821,104,200	68,656,470	74	92	\$838,017,410	77,446,205	79	92	8,789,735	\$16,913,207	0.655

Table 3-9 Model 5 results; intermediate-run, L-shaped cost function and even-flow constraints.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$1,773,965,600	95,978,784	57	92	\$1,826,363,200	111,856,110	68	92	15,877,326	\$52,397,626	0.785
	Middle	\$1,432,906,600	96,558,509	58	92	\$1,487,610,400	113,108,210	69	92	16,549,701	\$54,703,792	0.860
	Under-cut	\$1,125,982,800	96,515,318	59	92	\$1,171,780,400	113,492,640	69	92	16,977,322	\$45,797,591	0.755
Juvenile	Over-cut	\$291,837,180	15,050,182	42	92	\$302,631,870	17,467,764	48	92	2,417,582	\$10,794,694	0.905
	Middle	\$235,278,320	15,236,261	42	92	\$246,608,760	17,791,064	48	92	2,554,803	\$11,330,441	0.695
	Under-cut	\$183,313,210	15,196,668	43	92	\$193,282,280	17,848,175	48	92	2,651,507	\$9,969,071	0.885
Mature	Over-cut	\$1,295,530,300	75,022,385	71	92	\$1,318,422,100	83,734,167	75	92	8,711,782	\$22,891,816	0.685
	Middle	\$1,033,213,900	72,913,763	71	92	\$1,054,563,300	81,703,571	75	92	8,789,808	\$21,349,404	0.645
	Under-cut	\$773,074,340	68,656,470	74	92	\$787,873,170	77,446,205	79	92	8,789,735	\$14,798,830	0.650

The baseline model shows similar results to those from Model 3, the 6% even-flow model; values are simply scaled upwards. When the L-shaped cost function is engaged, the values of timber supply streams decrease by a small amount. This decrease is a result of simulations where harvest levels decline after uncertainty reduction, which causes capital to be under-utilized and per-unit capital costs to increase. The reason there is not a larger decrease in these values is because the period during which capital is under-utilized is so short, only 10 years. After this time the depreciated mill is re-built to a smaller capacity. Furthermore, much of these capital costs are discounted away.

Reducing uncertainty creates significant benefits in all scenarios except the mature forest with values discounted using a 6% interest rate. Only the mature forest that is initially middle-cut under the L-shaped cost function is an exception to this rule. Compared to the simulations using the flat cost function, incorporating capital constraint costs in the intermediate run causes greater benefits in the over-cut and middle scenarios. In the under-cut scenarios the benefits decrease, probably because there are fewer capital constraints in these scenarios. Finally, in all scenarios there is at least a 0.5 probability that the NPV will increase to a value higher than the mean NPV before uncertainty reduction.

3.7 Summary

It is important to keep in mind that the framework presented here provides a fairly narrow context to draw conclusions in. For instance, the models use a deciduous forest, and trees are subject to a decline in merchantability when they are 125 years old. Such is the case in much of Alberta, where large volumes of otherwise-merchantable deciduous

trees go un-harvested and begin to decay. A different forest type, such as spruce, for example, would decline at a much later age and would probably generate very different results. In addition, different interest rates, stumpage rates, policy constraints, age-class structures, or harvest regimes would probably also generate different results. In this respect, it is important to remember that it is the trends that are of importance here, as opposed to the absolute numbers.

Within this context, a key result is that in all simulations there is at least a 0.5 probability that reducing uncertainty will increase the NPV to a value higher than the mean NPV before uncertainty reduction. Furthermore, there are significant benefits to reducing uncertainty in all scenarios except the mature forest with a 6% interest rate. However, the Alberta forest industry operates on mainly mature land bases and faces interest rates of at least 6%. There are several questions and management implications that stem from this result.

First, under what conditions are there incentives to invest in reducing uncertainty in Alberta? There are significant incentives to invest in information collection when there is a 0% interest rate. These incentives increase as the sustained yield constraints are relaxed. This increase implies shadow costs associated with operating under sustained yield constraints because such constraints do not provide an optimum context for investment in reducing uncertainty.²⁹ Furthermore, the results from Model 5 imply that capital cost constraints have a minimal effect on incentives to invest in reducing uncertainty, with the exception of the mature forest scenario where the initial AAC is in the middle. The capital costs associated with varying harvest levels are small enough that

²⁹ van Kooten et al (1992) also found that flexible harvest policies are preferable in the face of uncertainty.

the benefits of uncertainty reduction do not change very much compared to situations where there are no capital cost implications.

Second, given these conditions, who has incentive to invest in reducing uncertainty in growth and yield estimates in Alberta? Industry faces interest rates of at least 6% and therefore, according the results within this framework, does not have such incentive. This is not to say that forest companies in Alberta do not want to invest in reducing uncertainty. Rather, it is the institutional framework that creates the effect that there may be no significant benefits associated with such investments. Society typically has a lower interest rate than industry and, according to these results, they may have significant incentive to invest in reducing uncertainty.

The lack of incentive for industry to invest in reducing uncertainty leads to a third implication. That is, without incentive to invest in reducing uncertainty, industry may prefer to operate with current knowledge. However, these results show that there may be a greater chance of harvesting at non-sustainable rates when uncertainty is not reduced.

The preceding implications lay the foundations for the following recommendation. That is, there may be an argument to have more government responsibility for research and information collection, given current forest policies.

CHAPTER 4 EMPIRICAL CASE STUDY

4.1 Introduction

This case study is an empirical application of the decision-making framework presented in Chapter 3. It examines the benefits of reducing uncertainty around a parameter for which empirical estimates of uncertainty exist. Specifically, temporary sample plot (TSP) data from an Alberta forest management unit (FMU) is used to conduct ex poste analyses on the benefits of reducing growth and yield uncertainty. Annual allowable cut (AAC) and the associated net present values (NPVs) of timber supply streams are again used as the criteria with which to measure the benefits of reducing uncertainty. The models again incorporate an assessment of how the benefits of reducing uncertainty are influenced by existing age-class structures, interest rates and the stringency of sustained yield constraints. The capital cost implications of varying harvest levels are not examined in this case study since it is difficult to obtain actual capital cost estimates for a forest products company. Furthermore, the results from Chapter 3 indicate that when these costs are applied within this framework, they do not have much effect on the benefits of uncertainty reduction. The models in this case study are set up using the same forest type, regeneration regime, planning horizon and stumpage value as in Chapter 3.

This chapter first describes how to measure current and reduced ex poste growth and yield uncertainty. Then, the results from four modeling scenarios are presented; even-flow sustained yield with a 0% interest rate, even flow with a 6% interest rate, current flexibility sustained yield with both interest rates, and twice flexibility with both interest rates. The chapter concludes with a brief discussion.

4.2 Current and Reduced Parameter Uncertainty

This case study examines the benefits of increasing sample size to reduce growth and yield uncertainty. Although it is not done here, subsequent applications of this framework could also examine the benefits of increased stratification, akin to the studies by Wang and Huang (2000). Weyerhaeuser Company Ltd. provided us with the TSP data for the W6 forest management unit (FMU) of their Edson, Alberta forest management agreement. There are 872 TSPs within the W6 FMU that were used to develop Weyerhaeuser's growth and yield curves for C and D density sites with percent conifer 60% and less. In an attempt to uncover the level of uncertainty for the yield curve used in these models, only those 86 plots with the same stratification as this particular curve are examined.

To compare the benefits of reducing uncertainty, this case study models two states of the world, just as in Chapter 3. In the first state of the world there is some initial level of uncertainty in growth and yield. After 10 years, low levels of investment in TSPs reduce this uncertainty by some amount. In the second state of the world there is the same level of initial uncertainty and, after 10 years, increased investment in TSPs reduces uncertainty even further.³⁰

To estimate the initial level of uncertainty in both states of the world, a random sample of 31 plots is drawn from the 86 TSPs. The parameters in the yield equations are re-estimated using these plots and non-linear regression procedures in S-PLUS® (version 6.1). Then, upper limit, lower limit and average yield tables are constructed using each parameter's standard error and 95% confidence interval. The result is three initial yield

³⁰ One could just as easily compare a zero investment in TSPs to a positive investment in TSPs. However, two levels of positive investment are used here so that the methods more closely parallel those in Chapter 3.

tables to assess a range of different starting conditions, which again represents the idea that forest practitioners probably would not know where they are within a current, ex poste level of uncertainty.

The three yield curves are shown in Figure 4-1 along with the "true" yield curve. The "true" yield table is created using the mean parameter values obtained from all 86 plots (Appendix B). The upper curve of initial uncertainty varies by up to 102% of the true curve, and the lower curve varies by up to 10% of the true curve. This variance differs from Chapter 3, where the upper and lower curves both varied by 50% of the mean curve. Furthermore, now that actual TSP data is being used, a shift in the sample mean of the yield values occurs when sample size is increased from 31 to 86.³¹ In Chapter 3, the erroneous yield tables were generated around the same mean, regardless of the level of uncertainty.

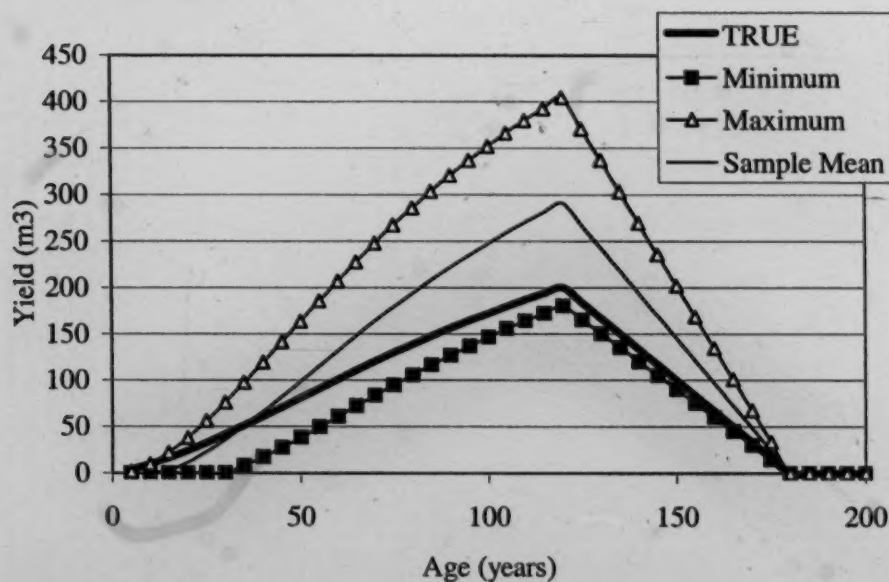


Figure 4-1 Maximum, minimum and middle yield curves based on 31 TSPs, shown with "true" yield curve.

³¹ Due to the central limit theorem, with repeated sampling this shift would not have occurred.

To estimate the reduced uncertainty in the first state of the world, a random sub-sample of 62 plots is drawn from the 86 TSPS. The parameters in the yield equations are again re-estimated using only these plots. Normally distributed random samples ($n = 200$) of the equation parameters are generated using the correlation matrices, means and standard errors associated with the parameters in these equations.³² Each set of parameters from these matrices is then used to re-estimate the yield table, resulting in a distribution of 200 erroneous yield curves that vary according to the standard error of the sub-sample.³³

The outer limits and mean of these yield curves are shown in Figure 4-2 along with the "true" yield curve. The curve reflecting the upper limit of initial uncertainty now varies by up to 34% of the true curve, and the curve reflecting the lower limit now varies by up to 46% of the true curve. Furthermore, as sample size increases from 31 to 62, the sample mean yield values come closer to the "true" curve.

³² This follows the methods suggested by Ulrich (2001), to generate bivariate random normal variates with a specified correlation matrix.

³³ This approach is similar to Eid (2000).

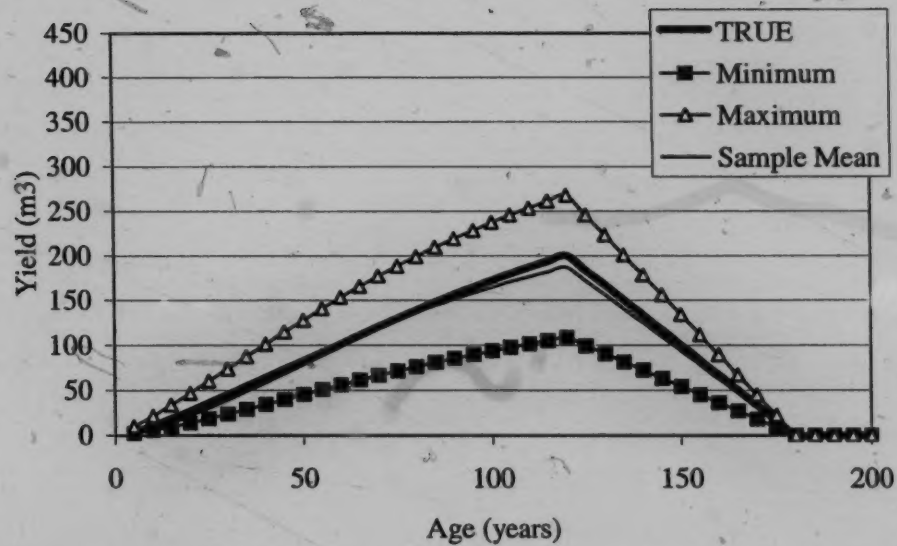


Figure 4-2 Maximum, minimum and middle yield curves based on 62 TSPs, shown with "true" yield curve.

All 86 plots are used to estimate the reduced uncertainty in the second state of the world. The same procedure is used to generate a distribution of 200 erroneous yield curves that vary according to the standard error of this full sample. The outer limits and mean of these yield curves are shown in Figure 4-3 along with the "true" yield curve. The upper and lower curves now vary by up to 30% of the true curve, and the sample mean now equals the "true" curve.

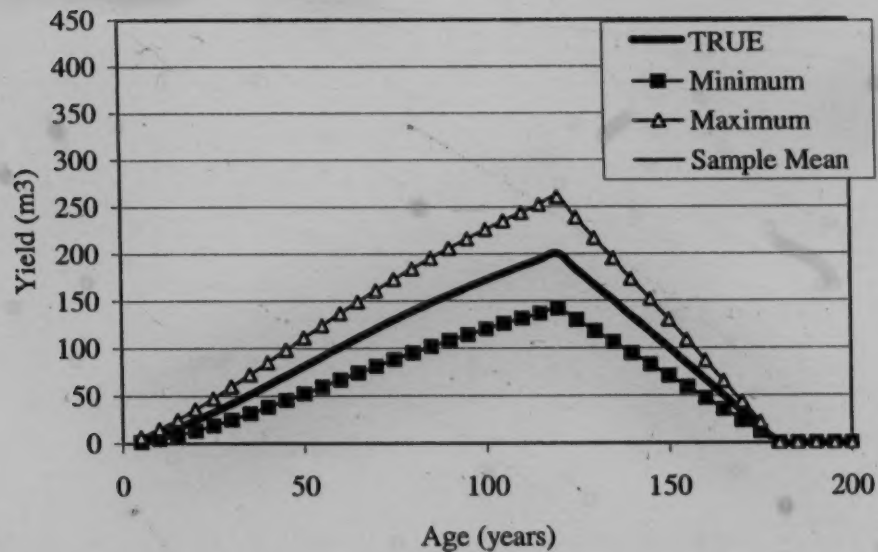


Figure 4-3 Maximum, minimum and middle yield curves based on 86 TSPs, shown with "true" yield curve.

Figure 4-4 is a decision tree similar to the one in Chapter 3 (Figure 3-5). It summarizes the modeling process in terms of harvest levels according to uncertainty in growth and yield and according to the level of investment in TSPs. It also includes the number of TSPs that are used to derive each set of yield estimates; i.e. the sources of information.

4.3 Simulation Results

4.3.1 Model 1: 0% Even flow

The results of the 0% even-flow simulations are similar to those from Chapter 3 and are presented in Table 4-1. The cumulative probability distribution (CPD) for the normal, over-cut forest is presented in Figure 4-5; the CPDs for all other scenarios show a similar shape and are therefore not included here.

Uncertainty in growth and yield, still present with new information, can once again result in non-sustainable harvest rates; i.e. timber supply crashes. In all forests, uncertainty reduction delays the timing of supply crashes, which significantly increases NPVs and average total harvest volumes. Also, the number of supply crashes is reduced, unlike Model 2 in Chapter 3, where the number of supply crashes remained constant. This difference is explained by the fact that the current ex poste uncertainty includes yield values that vary by up to 102% of the "true" yield curve, while in Chapter 3 they only varied by 50% of the mean values. Because there is a greater reduction in uncertainty from this initial level, the number of supply crashes is reduced.

Table 4-1 Model 1 results; even-flow constraints and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	30% Uncertainty				10% Uncertainty				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m3)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 366,198,540	73,239,703	48	93	\$ 419,243,460	83,848,688	50	90	10,608,985	\$ 53,044,928	0.485
	Middle	\$ 367,969,520	73,593,900	50	93	\$ 426,483,480	85,296,691	53	90	11,702,791	\$ 58,513,957	0.485
Juvenile	Under-cut	\$ 367,785,740	73,557,144	51	92	\$ 427,329,470	85,465,889	54	90	11,908,745	\$ 59,543,729	0.485
	Over-cut	\$ 57,280,224	11,456,044	35	93	\$ 65,787,433	13,157,486	37	90	1,701,442	\$ 8,507,209	0.490
Mature	Middle	\$ 57,898,960	11,579,791	36	93	\$ 67,330,879	13,466,175	38	90	1,886,384	\$ 9,431,919	0.490
	Under-cut	\$ 58,026,655	11,605,330	37	92	\$ 67,645,804	13,529,160	39	90	1,923,830	\$ 9,619,149	0.490
	Over-cut	\$ 318,323,350	63,664,667	67	91	\$ 356,699,310	71,339,859	69	90	7,675,192	\$ 38,375,961	0.430
	Middle	\$ 305,647,580	61,129,512	67	91	\$ 344,630,060	68,926,008	69	90	7,796,496	\$ 38,982,481	0.430
	Under-cut	\$ 293,503,390	58,700,674	67	91	\$ 332,729,780	66,545,952	69	90	7,845,278	\$ 39,226,394	0.430

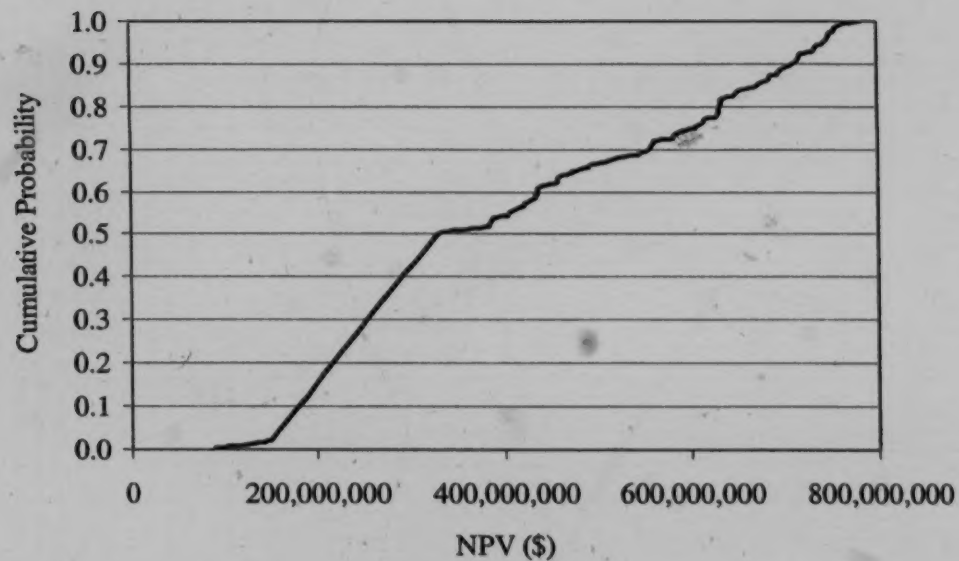


Figure 4-5 Cumulative probability distribution of NPVs; normal, over-cut forest, 0% interest rate and even-flow constraints.

Just as in Chapter 3, the timing of the supply crashes affects the total volume of the timber supply streams to differing degrees depending on existing age-class structures. For instance, in the juvenile forest there is a scarcity of existing merchantable timber and this again causes lower harvest levels, earlier supply crashes and relatively smaller total harvest volumes. In the mature forest, the abundance of merchantable timber again causes higher harvest levels, later supply crashes and higher over-all total harvest volumes. These differences in total volumes cause similar differences in total values.

Reducing uncertainty delays the timing of the timber supply crashes, which increases the total harvest volumes within the 200-year horizon and consequently increases the values. The supply crashes are delayed to a similar degree in the three forests, however the benefits from reducing uncertainty vary between the three, both in

terms of volumes and values. Benefits are smallest in the juvenile forest, larger in the mature and largest in the normal forest. Finally, the probabilities that reducing uncertainty will increase the NPVs to a value higher than the mean before uncertainty reduction ranges between 0.43 and 0.49; recall that in Chapter 3 these probabilities were all above 0.5. The lower probabilities are due to the similar levels of uncertainty for the two investment scenarios in the second state of the world.³⁴ In the first state of the world uncertainty is reduced to plus or minus 34% and 46%, and in the second state of the world it is reduced to plus or minus 30%; not a large difference.

4.3.2 Model 2: Introduce 6% interest rate

The results of the 6% even-flow simulations are presented in Table 4-2 and the CPD is in Figure 4-6. The CPDs for all other scenarios have a similar shape and are therefore not shown. The 6% interest rate affects the benefits of uncertainty reduction in several ways. To begin, although the volumes of the timber supply streams are the same, the values are significantly smaller than the 0% scenario because they are discounted. Furthermore, the benefits from uncertainty reduction are also much smaller because previous benefits from delaying and reducing supply crashes are now heavily discounted. This discounting causes the benefits in the mature forest to become insignificant. The probability that reducing uncertainty will increase the NPV to a value higher than the mean NPV before uncertainty reduction is greater than 0.5 in all simulations.

³⁴ To check this, additional models were constructed using the normal forest, and the reduced level of uncertainty in the second state of the world was manipulated to be 10% instead of 30%. The results were consistent with those from Chapter 3. The probability that the NPV would increase to a level higher than the mean NPV before uncertainty reduction was greater than 0.5 in all simulations.

Table 4-2 Model 2 results; even-flow constraints and 6% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	30% Uncertainty			10% Uncertainty			Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	
Normal	Over-cut	\$ 79,135,106	73,239,703	48	93	\$ 81,534,056	83,848,688	50	90	0.625
	Middle	\$ 65,489,304	73,593,900	50	93	\$ 68,124,511	85,296,691	53	90	0.620
	Under-cut	\$ 51,756,025	73,557,144	51	92	\$ 54,536,402	85,465,889	54	90	0.615
Juvenile	Over-cut	\$ 13,064,033	11,456,044	35	93	\$ 13,482,917	13,157,486	37	90	0.700
	Middle	\$ 10,791,197	11,579,791	36	93	\$ 11,253,030	13,466,175	38	90	0.690
	Under-cut	\$ 8,487,966	11,605,330	37	92	\$ 8,976,138	13,529,160	39	90	0.690
Mature	Over-cut	\$ 59,691,667	63,664,667	67	91	\$ 61,333,784	71,339,859	69	90	0.565
	Middle	\$ 48,983,484	61,129,512	67	91	\$ 50,651,285	68,926,008	69	90	0.565
	Under-cut	\$ 38,486,497	58,700,674	67	91	\$ 40,177,586	66,545,952	69	90	0.565

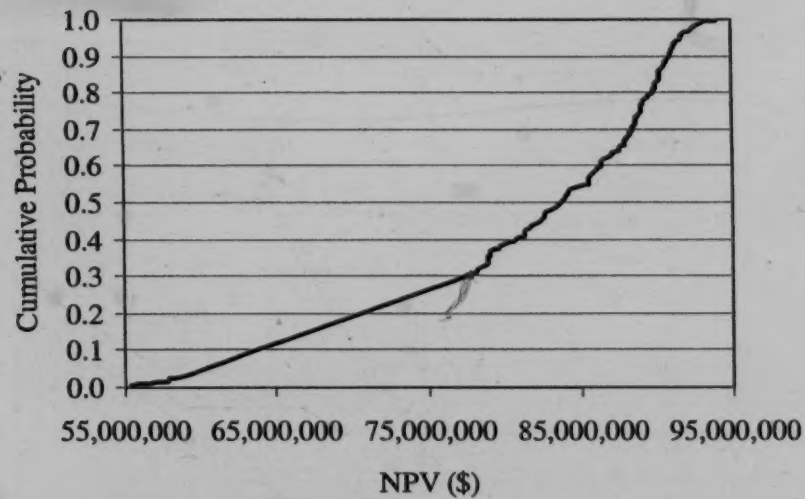


Figure 4-6 Cumulative probability distribution of NPVs; normal, over-cut forest, 6% interest rate, even-flow constraints.

4.3.3 Model 3: Relax sustained yield constraints

The two policy scenarios examined in Model 3 are current and twice flexibility, just as in Chapter 3. Table 4-3 through Table 4-6 show the NPVs and harvest volumes, and effects from reducing uncertainty, under the two policy scenarios and both interest rates.

Table 4-3 Model 3 results; current flexibility and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	
Normal	Over-cut	\$ 367,238,440	73,447,684	48	93	\$ 421,090,180	84,218,032	51	90	\$ 53,851,742
	Middle	\$ 371,394,620	74,278,919	49	92	\$ 427,580,800	85,516,155	52	90	\$ 56,186,182
	Under-cut	\$ 371,837,070	74,367,411	50	91	\$ 428,319,230	85,663,842	53	90	\$ 56,482,159
Juvenile	Over-cut	\$ 58,421,309	11,684,261	36	91	\$ 66,134,189	13,226,837	38	90	\$ 7,712,880
	Middle	\$ 59,128,500	11,825,699	37	91	\$ 67,615,197	13,523,039	40	90	\$ 8,486,698
	Under-cut	\$ 59,210,320	11,842,063	37	90	\$ 67,831,579	13,566,315	40	90	\$ 8,621,259
Mature	Over-cut	\$ 320,418,430	64,083,683	67	90	\$ 357,047,990	71,409,594	69	90	\$ 36,629,557
	Middle	\$ 308,031,940	61,606,385	67	90	\$ 345,048,920	69,009,781	69	90	\$ 37,016,981
	Under-cut	\$ 295,606,390	59,121,275	67	90	\$ 333,132,380	66,626,472	69	90	\$ 37,525,984

Table 4-4 Model 3 results; twice flexibility and 0% interest rate.
(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	
Normal	Over-cut	\$ 369,976,880	73,995,372	46	90	\$ 416,287,320	83,257,459	50	89	\$ 46,310,436
	Middle	\$ 381,841,650	76,368,325	48	89	\$ 434,538,320	86,907,659	53	88	\$ 52,696,670
	Under-cut	\$ 382,408,190	76,481,633	50	89	\$ 447,282,950	89,456,585	55	85	\$ 64,874,760
Juvenile	Over-cut	\$ 58,072,093	11,614,418	36	90	\$ 64,869,251	12,973,850	38	89	\$ 6,797,158
	Middle	\$ 60,253,853	12,050,770	37	89	\$ 67,922,161	13,584,431	40	89	\$ 7,668,308
	Under-cut	\$ 60,510,905	12,102,180	38	89	\$ 70,716,250	14,143,249	41	86	\$ 10,205,345
Mature	Over-cut	\$ 351,828,670	70,365,731	66	78	\$ 394,860,080	78,972,012	69	75	\$ 43,031,407
	Middle	\$ 338,733,800	67,746,755	67	78	\$ 382,335,540	76,467,103	69	75	\$ 43,601,740
	Under-cut	\$ 309,444,130	61,888,822	67	85	\$ 353,787,850	70,757,567	69	82	\$ 44,343,728

Table 4-5 Model 3 results; current flexibility and 6% interest rate.

(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 80,304,202	73,292,536	47	93	\$ 82,693,694	83,875,088	49	90	10,582,552	\$ 2,389,492	0.625
	Middle	\$ 66,410,528	73,524,706	49	93	\$ 69,125,485	85,287,571	51	90	11,762,865	\$ 2,714,957	0.625
	Under-cut	\$ 52,477,146	73,000,383	50	93	\$ 55,345,423	85,484,472	53	90	12,484,089	\$ 2,868,277	0.625
Juvenile	Over-cut	\$ 13,261,971	11,485,913	36	93	\$ 13,698,237	13,205,712	38	90	1,719,799	\$ 436,266	0.700
	Middle	\$ 10,960,506	11,604,239	37	93	\$ 11,427,586	13,496,857	39	90	1,892,618	\$ 467,080	0.700
	Under-cut	\$ 8,611,869	11,623,730	38	92	\$ 9,112,954	13,547,297	39	90	1,923,567	\$ 501,085	0.690
Mature	Over-cut	\$ 60,569,955	64,085,364	67	90	\$ 62,231,966	71,411,473	69	90	7,326,109	\$ 1,662,011	0.570
	Middle	\$ 49,713,475	61,606,936	67	90	\$ 51,394,168	69,010,389	69	90	7,403,453	\$ 1,680,692	0.570
	Under-cut	\$ 39,064,930	59,122,621	67	90	\$ 40,767,712	66,627,995	69	90	7,505,374	\$ 1,702,782	0.570

Table 4-6 Model 3 results; twice flexibility and 6% interest rate.

(Italicized numbers indicate a significant increase at the 95% level.)

Forest Type	Initial Harvest Scenario	Uncertainty Reduced to 30%				Uncertainty Reduced to 10%				Difference in Means of Harvest Volumes	Difference in Means of NPVs	Probability Uncertainty Reduction will Increase NPV
		Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes	Average NPV (\$)	Average Total Harvest Volume (m ³)	Average Year of Supply Crash	Number of Supply Crashes			
Normal	Over-cut	\$ 89,129,778	71,842,143	43	93	\$ 91,560,951	81,662,383	47	90	9,820,240	\$ 2,431,173	1.000
	Middle	\$ 73,558,863	73,616,708	46	93	\$ 76,183,664	84,791,543	49	90	11,174,835	\$ 2,624,802	0.985
	Under-cut	\$ 57,438,261	73,525,515	49	93	\$ 60,315,604	85,759,117	51	90	12,233,602	\$ 2,877,344	0.965
Juvenile	Over-cut	\$ 14,729,918	11,274,128	33	93	\$ 15,132,965	12,797,887	35	90	1,523,759	\$ 403,046	0.710
	Middle	\$ 12,123,794	11,574,126	36	93	\$ 12,596,688	13,404,441	37	90	1,830,315	\$ 472,895	0.700
	Under-cut	\$ 9,443,182	11,723,390	37	92	\$ 9,953,244	13,641,369	39	90	1,917,979	\$ 510,062	0.690
Mature	Over-cut	\$ 68,431,083	65,906,649	67	91	\$ 70,154,955	73,684,250	69	90	7,777,601	\$ 1,723,872	0.570
	Middle	\$ 55,632,826	63,011,445	67	91	\$ 57,383,137	70,852,139	69	90	7,840,694	\$ 1,750,310	0.570
	Under-cut	\$ 43,053,239	59,983,567	67	91	\$ 44,844,117	68,044,687	69	90	8,061,120	\$ 1,790,877	0.570

In Chapter 3, the benefits from reducing uncertainty increased in all scenarios when sustained yield constraints were relaxed. However, in this case study, the benefits do not change much with reduced constraints. This lack of response is again due to the similar levels of uncertainty for both investment scenarios in the second state of the world.³⁵ Similar to Chapter 3, reducing uncertainty significantly increases the values of timber supply streams in all scenarios except in the mature forest when values are discounted with a 6% interest rate; this has been a consistent result thus far. Finally, the probability that uncertainty reduction will increase the NPV to a value greater than the mean NPV before uncertainty reduction is less than 0.5 in the 0% scenarios and greater than 0.5 in the 6% scenarios. Again, the low probabilities in the 0% scenarios are probably due to the similar levels of uncertainty for both investment scenarios in the second state of the world. The CPDs for the 0% scenarios are similar in shape to Figure 4-5, and the CPDs for the 6% scenarios are similar in shape to Figure 4-6.

4.4 Summary

The key results from this case study strengthen those from Chapter 3; there are significant benefits to reducing growth and yield uncertainty in all scenarios except the mature forest with a 6% interest rate.

Many of the management implications that stem from this result are similar to those from Chapter 3. For instance, there are significant incentives to invest in information collection in Alberta when there is a 0% interest rate, which again implies that industry may not have incentive to invest in reducing uncertainty within the current

³⁵ This was checked using the supplementary models with uncertainty in the second state of the world manipulated to 10%, instead of 30%. Again, the results were consistent with those from Chapter 3; the benefits from reducing uncertainty increased as sustained yield constraints relax.

institutional framework. Since society may have such an incentive, there may still be an argument for more government responsibility for research and information collection.

The trend apparent in Chapter 3, that benefits from reducing uncertainty increase as sustained yield constraints are relaxed, is not as pronounced here. This is because the reduced levels of uncertainty in the two states of the world are very similar, whereas in Chapter 3 there was a marked difference. Therefore, with larger reductions in uncertainty in the second state of the world, one can still infer that operating under strict sustained yield constraints may not provide an optimum context for investment in information collection.

The high level of uncertainty still present in the second state of the world also accounts for the difference in probabilities compared to Chapter 3. In all simulations in Chapter 3, there were greater than 0.5 probabilities that uncertainty reduction would increase the NPV to a value larger than the mean NPV before uncertainty reduction. Here, however, the 0% simulations have probabilities less than 0.5. Again, with larger reductions in uncertainty in the second state of the world, the trend from Chapter 3 reappears.

CHAPTER 5 METHODS FOR A SUBJECTIVE CASE STUDY

5.1 Introduction

This chapter describes how to use professional judgment to estimate current and reduced levels of uncertainty around a timber supply parameter. Subjective methods like this can be used for parameters where empirical estimates of uncertainty do not exist. They can also be used for parameters where empirical estimates of current uncertainty *do* exist, in which case the professional judgment can be used to obtain estimates of the potential to reduce that uncertainty. In either case, the implied method of reducing uncertainty is via research as opposed to increased sampling. To maintain consistency within this paper, the parameter examined in this chapter is again volume projections. To generate more broadly applicable results, this parameter is considered in two different contexts. One context assumes that current estimates of uncertainty exist, and the other context assumes that such estimates do not exist.

5.2 Estimating Current and Reduced Uncertainty via Questionnaire

Qualified experts can be asked via questionnaire to estimate current and potentially reduced uncertainty in growth and yield³⁶. Two possible questionnaire formats are discussed in the following sections; both questionnaires are included in Appendix C. In Questionnaire #1, respondents are asked to estimate the current uncertainty around a growth and yield curve and to estimate how much that uncertainty could be reduced with research. This questionnaire can be used if empirical estimates of uncertainty around a parameter do not exist. In Questionnaire #2, the current level of

³⁶ This draws on the methods of van Kooten et al (1992), who suggested asking qualified professionals to provide estimates of current and potentially reduced uncertainty.

uncertainty is provided and, again, respondents are asked to estimate the potential to reduce that uncertainty. This questionnaire can be used when empirical estimates of uncertainty do exist.

Both questionnaires ask for estimates on the potential to reduce uncertainty in two different ways. The first way provides the level of uncertainty reduction as background to the question. It asks respondents how much it would cost, in dollars of research funding, and how long it would take, in years of research, to achieve that reduction. The second way provides the funding level and research time as background to the question. It asks what level of uncertainty reduction could be achieved with those resources. It is hoped that soliciting information on reducing uncertainty in both of these ways, versus just one or the other, will encourage more thoughtful responses. Furthermore, this approach may temper the possibility that the estimated benefits from reducing uncertainty can be diminished if current uncertainty estimates are overconfident.³⁷ Finally, multiple responses from experts can be averaged.³⁸

5.3 Cost Estimates of Uncertainty Reduction

The research funding levels for the questionnaires can be based on typical growth and yield grants from a relevant university. These funding levels can be augmented with additional costs including in-kind contributions, overhead costs, and costs of additional

³⁷ Hammitt and Shlyakhter (1999) caution that the estimated benefit of reducing uncertainty can be diminished if current uncertainty estimates are overconfident, or too tight, since the value of information is greater if prior uncertainty is greater.

³⁸ There are several suggested methods to combine expert opinions (Cook, 1991; Jacobs, 1995; Clemen and Windkler, 1997). However, there is limited evidence available to support one method as superior to others, suggesting that simple averages may be adequate (Clemen and Winkler, 1997).

person-hours. This information can be obtained from university administration staff in terms of, for example, in-kind costs per \$1000 of research costs.

5.4 Summary

To estimate the benefits of reduced uncertainty, the uncertainty estimates obtained using subjective methods can be used in the same sensitivity analysis framework that was presented in Chapter 3. Then, the total costs (research funding plus in-kind costs) can be weighed against the NPVs of uncertainty reduction to obtain a net benefit of research.

CHAPTER 6 CONCLUSION

There are two important contributions from this project. The first contribution is a framework to direct research topic selection, or data collection, according to where reducing uncertainty may have the greatest benefit. The second contribution is the investigation into how existing age-class structures, interest rates and institutional constraints may affect such benefits.

The framework to direct research topic selection was motivated by the numerous sources of biological, political, economic and technological uncertainty in forest management, all of which are exacerbated by the long-term planning horizon the forest sector faces. Although methods have been developed that attempt to incorporate these uncertainties into optimization solutions, the mistakes that may ensue can still have potentially costly impacts. Building on the methods of Eid (2000), the framework presented here may provide a link between assessing the potential costs of uncertainty, and influencing the direction of information collection so as to reduce those uncertainties. The framework provides more explicit information for research topic selection and data collection in forest management, which hopefully improves upon the current, rather ad hoc, methods of selecting research topics.

Although this framework can apply to any forest resource, it is applied here in the context of timber supply. By simulating differing patterns of available timber supply over time, given current and potentially reduced levels of uncertainty, the following questions were addressed. How much can information reduce growth and yield uncertainty, thereby reducing mistakes in timber supply projections? Also, what are the benefits, in terms of net present values, of reducing mistakes in timber supply projections

within the context of sustained yield policies? Results obtained from using this framework can be compared to the estimated costs of reducing uncertainty, to obtain a net benefit of research. Subsequent applications of this framework can explore different forest resource contexts, different institutional constraints, different sources of uncertainty, and different methods of reducing uncertainty. Increased stratification, for instance, is an alternative to increased sampling as a means to reduce uncertainty.

The framework as presented provided the opportunity to examine how the benefits of reducing uncertainty are influenced by key factors such as existing age-class structures, interest rates, the stringency of sustained yield constraints, and capital cost implications. It is important to view the results of this study with the context in mind. Changing the forest types, interest rates and institutional constraints could generate different outcomes. However, the trends that emerge from this context elicit some provocative ideas.

The results from both the theoretical simulations and case study show that benefits from reducing uncertainty in growth and yield estimates depend largely on interest rates, existing age-class structures and institutional constraints. Significant benefits exist in all scenarios, in both Chapters 3 and 4, except the mature forest with values discounted by a 6% interest rate. However, the Alberta forest industry operates on land bases comprised mainly of mature trees, and faces interest rates of at least 6%. The questions and management implications that stem from this result are threefold.

First, where do incentives exist to reduce uncertainty in growth and yield estimates? There are significant incentives to invest in growth and yield information collection in Alberta when there is a 0% interest rate. These incentives increase as the

sustained yield constraints are relaxed, implying another set of shadow costs associated with operating under sustained yield constraints. These shadow costs are dynamic because the sustained yield constraints influence investment in reducing uncertainty, which in turn influences timber supply streams in the future.³⁹ Finally, the results from Model 5, in Chapter 3, imply that capital cost constraints have a minimal effect on incentives to invest in reducing uncertainty. The capital costs associated with varying harvest levels are small enough that the benefits of uncertainty reduction do not change very much compared to situations where there are no capital cost implications.

Second, given these conditions, who has incentive to invest in reducing uncertainty in growth and yield estimates in Alberta? Industry faces interest rates of at least 6% and therefore, given these results, does not have such incentive. That is not to say that forest companies in Alberta do not want to invest in reducing uncertainty. Rather, it is the institutional framework that creates the effect that incentives to make such investments are reduced. Society typically has a lower interest rate than industry and therefore, according to these results, they have significant incentive to invest in reducing uncertainty.

The lack of incentive for industry to invest in reducing uncertainty leads to the third implication. That is, without incentive to invest in reducing uncertainty, industry may prefer to operate at status quo. However, these results show that there may be a greater chance of harvesting at non-sustainable rates when there is not an increased investment to reduce uncertainty.

³⁹ Boyd and Hyde (1989) suggest two types of shadow costs associated with sustained yield. Static costs may refer to transaction costs that exceed the benefits of the regulation. Dynamic costs, on the other hand, include "the costs imposed by new regulations as they alter future expectations and the costs imposed by the general inflexibility of regulations once imposed".

The upshot of this discussion is there may be an argument to have more government responsibility for research and data collection. Society can influence government, who can in turn influence industry through policy and legislation, to make such investments. However, some final questions remain. For instance, is society aware that incentives to invest in research do not exist for industry within the current institutional context? Are they aware of the implications that may be associated with not reducing uncertainty? Furthermore, who should bear the costs of research investments?

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APPENDIX A

Yield curve, presented in 200, five-year periods, for deciduous stands in both upper and lower foothills natural subregions of Alberta with medium site class, C-density canopies and 10% conifer. Volumes are in cubic meters.

0	0	0	0	0	9.5	24.2	39.0	53.5	67.5
80.8	93.4	105.3	116.5	127.0	137.0	146.3	155.0	163.2	170.9
178.0	184.7	191.0	196.8	202.1	185.3	168.4	151.6	134.8	117.9
101.1	84.2	67.4	50.5	33.7	16.8	0	0	0	0

APPENDIX B

Mean yield curve, presented in 200, five-year periods, derived from the 86 temporary sample plots within the following strata: deciduous stands, both upper and lower foothills natural subregions of Alberta, medium site class, C-density canopies and 10% conifer. Volumes are in cubic meters.

4.1	9.6	16.4	24.2	32.7	41.9	51.4	61.2	71.2	81.2
91.3	101.2	111.0	120.6	130.0	139.0	147.9	156.4	164.5	172.4
179.9	187.1	193.9	200.4	183.7	167.0	150.3	133.6	116.9	100.2
83.5	66.8	50.1	33.4	16.7	0	0	0	0	0

APPENDIX C

Questionnaire #1

Please answer the following questions based on your own experience, knowledge and opinion.

The yield curve in the following questions applies to deciduous-dominated sites with medium site quality, C density stands and 10% conifer, in both the upper and lower foothills natural subregion of Alberta. According to temporary sample plot data, this yield curve represents some of the most commonly occurring sites on the Weyerhaeuser Edson W6 forest management unit. This curve was estimated for Weyerhaeuser Company Ltd. by Timberline Forest Inventory Consultants in Edmonton. The curve was developed by "stratifying volume sampling plots according to broad inventory cover groups within natural subregions, and then applying nonlinear volume estimation functions that incorporated stand age, site and conifer percentage... after subjective deletions there were 2016 plots used for yield projections" (Timberline Forest Inventory Consultants, 2001). Of these, 872 plots were used to estimate the equations that apply to the yield curve specified in this questionnaire.

Part 1.

1. Please estimate the current level of uncertainty for the deciduous yield curve shown on the attached page. Please provide your answer by drawing three additional yield curves on the same figure:

1. one consisting of yield values you consider to form the upper bounds of the current 95% confidence interval;
2. one consisting of yield values you consider to form the lower bounds of the current 95% confidence interval; and
3. one consisting of yield values you consider to represent the most likely values, if you believe them to be different than the existing yield curve.

2. Assume that you could select the best growth and yield researchers to use empirical and process models to develop a better fundamental understanding of the mechanisms behind growth and yield. How much do you think it would cost, in dollars, and how long do you think it would take, in years, to reduce the uncertainty you estimated around this yield curve by one third?⁴⁰

3. How much do you think it would cost and how long do you think it would take to reduce the uncertainty around this yield curve, from the initial level you estimated in question 1, by two thirds?

⁴⁰ All italicized numbers and amounts can be changed to suit the survey.

Part 2.

1. Assume the same current level of uncertainty for the deciduous yield curve as you provided in Part 1. Assume again that you could select the best growth and yield researchers to use empirical and process models to develop a better fundamental understanding of the mechanisms behind growth and yield. If those researchers were given \$500,000 of research funding, how much do you think the uncertainty you estimated around this yield curve could be reduced after 5 years of research?

2. If the same researchers were given \$1,000,000 of research funding, how much do you think uncertainty around this yield curve could be reduced, from the initial level you estimated in question 1, after 10 years of research?

REFERENCES

Timberline Forest Inventory Consultants, 2001. Natural Stand Yield Curves Development and Results: Weyerhaeuser Edson Forest Management Agreement Area. Edmonton, Alberta. 47 pp.

Questionnaire #2

Please answer the following questions based on your own experience, knowledge and opinion.

The yield curve in the following questions applies to deciduous-dominated sites with medium site quality, C density stands and 10% conifer, in both the upper and lower foothills natural subregion of Alberta. According to temporary sample plot data, this yield curve represents some of the most commonly occurring sites on the Weyerhaeuser Edson W6 forest management unit. This curve was estimated for Weyerhaeuser Company Ltd. by Timberline Forest Inventory Consultants in Edmonton. The curve was developed by "stratifying volume sampling plots according to broad inventory cover groups within natural subregions, and then applying nonlinear volume estimation functions that incorporated stand age, site and conifer percentage... after subjective deletions there were 2016 plots used for yield projections" (Timberline Forest Inventory Consultants, 2001). Of these, 872 plots were used to estimate the equations that apply to the yield curve specified in this questionnaire.

Part 1

1. Based on available temporary sample plot data I have estimated that the current 95% confidence interval around the mean yield curve in the figure below includes yield values that are up to 50% higher than the curve, down to 50% lower than the curve, and anywhere in between those two bounds. Assume that you could select the best growth and yield researchers to use empirical and process models to develop a better fundamental understanding of the mechanisms behind growth and yield. How much do you think it would cost, in dollars, and how long do you think it would take, in years, to reduce the uncertainty around this yield curve to $\pm 30\%$?

2. How much do you think it would cost and how long do you think it would take to reduce the uncertainty around this yield curve from $\pm 50\%$ to $\pm 10\%$?

Part 2

1. Consider the same level of current uncertainty around the same yield curve as in Part 1 of this questionnaire. Assume again that you could select the best growth and yield researchers to use empirical and process models to develop a better fundamental understanding of the mechanisms behind growth and yield. If these researchers were given \$500,000 of research funding how much do you think uncertainty around this yield curve could be reduced after 5 years of research?

2. If the same researchers were given \$1,000,000 of research funding how much do you think uncertainty around this yield curve could be reduced, from the current level, after 10 years of research?

REFERENCES

Timberline Forest Inventory Consultants, 2001. Natural Stand Yield Curves Development and Results: Weyerhaeuser Edson Forest Management Agreement Area. Edmonton, Alberta. 47 pp.

Yield curve:

